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BIOACCUMULATION OF RADIONUCLIDES ON GRANITIC OUTCROPS IN THE GEORGIA PIEDMONT

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Athens, Georgia

October 1966

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Final Report

on the

BIOACCUMULATION OF RADIONUCLIDES

ON

GRANITIC OUTCROPS

in the

Georgia Piedmont

Grant Number RH-00117-04

Division Radiological Health
Public Health Service
Washington, D. C.

Gaythe L. Plummer
Department of Botany

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PREFACE

The "moratorium period" from 1958 through August 1961--when tests of atomic energy devices in the atmosphere were at a minimum level--was a time when many atomic energy workers were busy evaluating results from completed experiments. Furthermore, atomic energy biologists around the world were extending their studies by investigating all sorts of bio-geo-chemical cyclings, the potentials of radionuclides and particularly the ultimate biological effects. Careful studies under controlled conditions were emphasized in the field and laboratory. Riding the crest of a vigorous research wave were ecological studies about radioactive wastes that pollute air, water and soil. Attention was given to actions as well as interactions both upon populations and within ecological systems.

Radioactivity as found in naturally-occurring nuclides had received considerable attention because of its contribution, along with that from the fallout nuclides, to the new levels of background radiation. Food-network studies in the Alaskan tundra were nearly completed in 1961 when Russian atomic tests in the arctic produced enough radioactive fallout within tundra ecological systems to cause American biologists to begin a complete re-evaluation of background radioactivity as well as a fresh start in the biogeo-chemical cycling of ^{137}Cesium and ^{90}Strontium.

Meanwhile, during the 1958-1961 moratorium the outcrop project was developed and a proposal was submitted to the Public Health Service on February 23, 1960 to study accumulations of radionuclides by plants and animals inhabiting granitic outcrop ecosystems. The proposal was originally approved by the council of June 1960 and was activated more than a year later, on November 1, 1961, with support recommended for a 3-year study period. Continuations, supplemental appropriations and extensions permitted the project to function until June 30, 1966.

A few excerpts from the proposal, when compared with events of the past 4 1/2 years, indicate that plan of study in 1959 was appropriate to meet the events which followed some time later. When the period of unanticipated and unprecedented quantities of fallout began in 1961, the plan of study coincided nicely with certain investigations of obvious necessity. Several paragraphs from the proposal highlight the rationale at that time:

> "The granite rock outcrops are interesting and unique ecological systems with several endemic species of plants and a few animals. The granite contains certain radionuclides; and ... fallout is, or has been comparatively high.
>
> The outcrops suggest some interesting problems in environmental radiobiology because some of the lichens ... pre-date the atomic era and have grown with ... fallout ...

This project proposes to assay the granites, the gneisses, the residual soils, certain species of plants, insects and small mammals for quantities of radionuclides. The general purpose would cover biogeochemical studies on body burdens, food chains, rates of assimilation, as well as decomposition, and the fate of the radioisotopes within the ecosystem. The cycling of Sr-90 is of particular interest; the ratio of Sr-90 to that of other outstanding radionuclides is relevant. The status of an "equilibrium cycle" is also significant.

(As for significance ...) these investigations are intended to help clarify some of the biogeochemical processes involved in the bioaccumulation of fallout materials in an environmental system. The biological fate of ... isotopes (on) outcrops has not been investigated. ... Through these investigations we hope to learn if an equilibrium has been reached between the rate of assimilation of radionuclides ... and the return through decomposition of the biota.

... certain studies will need to be defined more distinctly by the use of some radioisotopes to trace food chains or nutrient cycles.

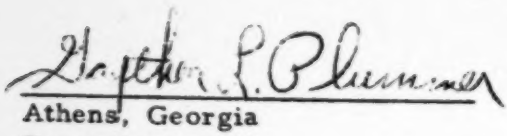
A graduate assistant will be assigned to one part of the problem ... (to survey the vegetation, to study Sr-90 uptake and to work toward the M.S. degree in botany) ... "

Although RH-00117 was designed for a single research project both time and the abundance of atmospheric detonations indicated that several subprojects were more appropriate. In all 12 major subprojects are described in this report; several minor subprojects were developed but the results have been generally incorporated into the larger projects that developed. Nearly every objective in the original plan has been reached in one form or another.

The staff associated with the project consisted primarily of graduate research assistants and research technicians. Each graduate research assistant completed at least one degree (*) as part of independent studies while assisting in the field and laboratory. I am grateful for the perseverence of Arthur R. Garrett, Jr., BS, MS*, PhD; Frank A. Helseth, BS, MS*, PhD*; J. Daniel Pittillo, BS, MS, PhD*; Jerry C. Ritchie, AB, MS, PhD*; James N. Skeen, BS, MS*; and Thomas M. Pullen, Jr., BS, MS*. The part-time technicians frequently spent full-time in the field, especially during the summers: J. Donald Blake, BS; Fred M. Veal, BS, MS*; and James B. Moncrief, Jr., BS*, DDS. The senior technical consultants who functioned without direct pay from the project included

John T. McGinnis, PhD statistician and radiation botanist in the Institute of Radiation Ecology, University of Gerogia and Mr. Richard M. Fetz, Director, Division of Radiological Health, Georgia Department of Health, Atlanta. Others were involved, of course; to all I extend my appreciation and thanks for several years of very interesting work.

For all results, data, and information cited from reports, thesis and dissertations by graduate students I accept full responsibility.



Athens, Georgia
December, 1966

INTRODUCTION

Widespread radioactive fallout resulted especially from atmospheric nuclear testing between September 1961 and September 1963. The peak of fallout in the Georgia Piedmont came in May and June 1963. Monitoring over the years has shown that accumulation of 90-strontium has been relatively high--140 mCi/miles^2--compared to other places in the United States.

The granitic outcrops within the Piedmont physiographic province are ideal ecological systems for investigating biogeochemical activities of radioisotopes because the impermeable rocks undulate and conduct surplus water through a series of small ecosystems which vary floristically from simple to complex communities. Both fallout and naturally occurring radionuclides are present and available for incorporation into plant and then animal tissues.

The movements of radionuclides from soils through plants and into the herbivores as well as the carnivores are relatively easy to study on the granitic outcrops because the food-chains are much more simple than those in fields and forests where species diversity is greater than on the outcrops. On the other hand, about the only animals that reside entirely on the outcrops are a few grasshoppers and lizards. The flow of any radioisotope from the soil to a carnivore is limited primarily because that animal includes more ecological systems within its territory than the outcrops alone. So, the prevailing difficulty in food-network studies on the outcrops was associated with matters that dealt with determination of areas of occurrence, territories, ranges and other areas of influence.

Fallout particles are distributed without uniformity throughout any ecological system. Moreover, fallout has not been distributed uniformily from one outcrop to another. Various environmental factors affect the location and distribution of radionuclides from place to place. Each granitic outcrops differed from the other in geological age although several outcrops are believed to be very closely related geomorphologically. Nevertheless, once these and other such variabilities are understood, certain kinds of information and observations may be synthesized temporarily in order to arrive at problems in proper perspective; then, once an over-view in perspective is achieved details readily evolve, providing such details warrant particular isolation.

This project attempted to evaluate concentrations of various radionuclides within components of ecological systems directly and indirectly connected with the granitic outcrops. When concentrations were known, as well as something about variabilities, attempts were made to explain actions and interactions between various radioisotopes, soils, plants, water-flow through communities and concentrations within components of the respective ecosystems. The purposes have been to document concentrations of radioisotopes within the biogeochemical cycling of one kind of an ecological system.

MATERIALS AND METHODS

Habitats.

Granitic flat-rocks extend from Virginia to Alabama throughout a zone in the Piedmont region that lies just west and north of the Fall Line. The area extends about 700 miles long and 120 miles wide. The zone is approximately coextensive with that in which true granites are found in the region, but the flat-rocks are frequently gneisses, sometimes schists, or more commonly porphyritic granites and gneisses. The total amount of bedrock appearing at the surface is unknown, but in Georgia, where the largest outcrops occur, igneous rocks probably cover more than 6000 acres. Small outcrops number in the thousands and are too small to be recognized as substantial areas of importance to this study. Outcrops of 10 to 40 acres are common; they provided conditions most suitable to these investigations. The largest outcrop--Stone Mountain--includes 400 acres and is unique among the outcrops; it was not included as a major environment in this study because it was being developed into a public recreation area.

A typical outcrop is generally the flat-rock type that slopes gently --0-10%--toward a woodlot with ordinary drainage ways. The surface of the flat-rock undulates with a series of depressions surrounded with lichen-covered hard rock. The depressions, caused by macro-exfoliation from freezing and thawing, are small nearest the uplands and gradually increase in size down-hill as water activity over the years became more vigerous. Not only are the pits larger on the lowland sites, but the soils in them are deeper. Soil materials have accumulated within the depressions depending upon the amount of water activity, the degree of slope, the elevation of the pit and other factors.

The lichen-covered (Parmelia conspersa) upland rocks contribute to the soil-forming processes. Otherwise soil depth varies from upland pits to lowland pits and plant communities vary accordingly. Soil depth in large pits--100 square feet--is zoned radially and stratified vertically--8-20 inches--and plant communities are associated with the soil depth. Upland depressions are occupied by very shallow soils, perhpas no more than one inch deep, that support a simple system with a one-species annual plant. Lowland depressions support complexed communities with multi-taxa perennials depending upon the size of the area, depth of soil and amount of incoming water. Between the extremes in elevations, or pit sizes, lies a variety of intermediate communities with habitats that support plants pecularly associated with the site. The biota from one outcrop to another does not vary a great deal; neither does it vary from one side of an outcrop to another. Most organisms inhabiting the outcrops are adapted to withstand heat in excess of 100°F and the lichens are often exposed to 155°F heat. Conversely, organisms respond rapidly to available moisture and when water comes to a habitat the plants quickly incorporate moisture whether that water is in the form of soil water, dew, or high humidity.

Radioactive fallout may cover an outcrop rather uniformly depending upon the size of the flatrock, upon the size of the thunderstorm, and duration of rainfall. During the peak fallout periods in spring the weather patterns have been typically associated with contintental polar air masses and frontal activities; in summer and autumn, on the other hand, fallout is associated the local thunderstorms that derive moisture from maritime air masses usually from the Gulf. Between 1959 and 1965 annual precipitation in the Atlanta, Georgia, area was above normal (Table 1). In 1964 precipitation at Athens was more than 70"--or 22" above normal.

Excess water on the outcrops, that not absorbed by the carpet of Parmelia lichen and other vegetation, is normally funnelled by the topography from pit to pit through a series of small ecological systems into larger ones. Along the way substances, are, presumably, added or subtracted from the transient waters. One hypothesis at the outset of the project was that radionuclides were collected also by components of an ecological system independently and differentially from any other such system along the way. Furthermore, certain annual plants would collect radionuclides at one time of the year and release them, perhaps at different rates, at another time of the year during decay of humus. Thus, biogeochemical cycling became an ecological process that was relatively simple to study, particularly within the outcrop ecological systems that were much less complex than fields, forests, lakes and streams.

Outcrops used in these projects were within a 70-mile radius from Athens, Georgia. No two outcrops were exactly the same; that is, topographic and physiographic variations occurred wherever similar geological materials were found. Ten outcrops were finally selected as most typical of all others; yet, each outcrop was a unique ecological system within the strictest interpretations.

Procedures.

Collections of biological materials began in January 1962 with an assumption that radioactive fallout had been, and probably would be, reasonably uniform over most of the outcrops. Every species of plant was sampled from 15 or more outcrops throughout the summer of 1962. Vertebrates and invertebrate animals were collected as frequently as they could be found. Preliminary analyses for radionuclides indicated 1) that sampling procedures were unnecessarily detailed; 2) that isotope concentrations in certain species were of insufficient concentrations to indicate promising patterns of importance; and 3) that selective sampling of indicator species would yield results and information representative of biogeochemical patterns on the outcrops as a whole. Sampling routines were adjusted by November 1962 and throughout 1963. When the peak fallout period occurred early in 1963 the biota on the outcrops were collected so that sampling procedures followed the most typical pattern of cycling. During 1963, attention centered on those organisms known to hold the most fallout during 1962.

Prior to ashing the biological materials were cleaned in one way or another, such as screening lichens of soils; they were ground in a Wiley-mill or otherwise mixed uniformly when appropriate; and samples of a species may have been composited from several outcrops if such a practice gave the most useful information. Combustible materials were concentrated by dry-ashing at 450°C. Sometimes samples of ash from a species collected at different outcrops were combined if that method of compositing were most suitable. One to four grams of ash were used for radioisotope analyses. Replications were applied as each case warranted particular kind of varification.

Gamma-ray spectrometric analyses provided the most direct analysis for several radioisotopes. Assays were made with a 400-channel pulse-height analyzer (Technical Measurements Corporation) usually using 10 kev per pulse height unit across 200 channels; sometimes 14 kev/PHU were used. The detector, a well-type 3 x 3 in. NaI(Tl) crystal (Harshaw), was housed in a 12 x 16 x 19 in. cave having lead walls 4 in. thick. Data were recorded on a cathode-ray tube and Polaroid camera and a data print-out, tape-recording readback system. During the spring of 1965 detection capabilities were increased with the addition of a solid 4 x 4 in. NaI(Tl) crystal (Harshaw) housed in a new cave with 36 x 36 x 36 in. inside dimensions. The lead walls were lined with copper to reduce x-ray interactions and background radioactivity. This new facility permitted gamma-ray analysis on bulk samples and reduced somewhat the necessity for concentrating biological materials; furthermore, it made detection of high-energy gamma-emitting isotopes much more reliable, particularly thorium and daughter nuclides as well as 40-potassium. For standard spectra from gamma-emitting fallout radionuclides a set of absolutely (±5%) standardized radioisotopes were obtained from Amersham, England. The library of reference nuclides eventually grew to 25 isotopes including some analyzed samples of naturally-occurring uranium and thorium.

Counting geometries varied depending upon the materials to be counted. Glass vials of 1 in. diameter were used for samples of ash; plastic boxes 3 in. diameter and 1 in. high were used for fresh materials particularly samples from deer organs; and large Marinelli beakers, 5-liter size, were used to count rocks, screened soils and other samples of bulk materials. Counting times ranged from 100 to 1000 minutes per sample.

Data from a sample of material analyzed by the gamma-ray spectrometer were transfered manually to punch-cards for computer analysis. Each complex gamma-ray spectrum was resolved quantitatively for individual isotopes by a computer program that used the linear least-square method for fitting 8-10 reference spectra for known fallout isotopes to a sample-problem spectrum containing at least the common fallout isotopes. A computer program was obtained from the Los Alamos Scientific Laboratory, adapted to our IBM 7094 in Fortran IV language and put into operation during January 1965. Prior to that time estimates of isotope concentrations were

obtained by an electronic spectrum stripping accessory equipment adapted to the TMC pulse-height analyzer. The addition of the computer program, coming as late as it did, gave the project the necessary facility for responsible data reduction. Since then all data have been revised and checked by computer techniques.

Analyses for 90-strontium on 171 four-gram samples of ash were made by Isotopes, Inc., Westwood, New Jersey. This commercial processor was much more capable of handling ^{90}Sr analysis than our laboratory; furthermore, the service was prompt and the data were reliable.

Deer food chain studies.

Deer browse and animal tissues were collected from Greene County, Georgia, the site of a national forest. The upland forest is of the oak-hickory type with oak-pine communities widespread; sweetgum-tuliptree occurs in the bottomlands and many old fields are scattered thoughout the territory. Twenty-nine genera and species of browse were collected on the basis of experienced investigators as to desirability of each kind of plant. The "desirable" species were lumped into one catagory and the "undesirable" --or least eaten plants--into another. Collections were randomized from widespread areas frequented by deer. Each kind of plant was analyzed for particular radionuclides before any data were composited.

During the hunting season tissues were collected from killed animals that passed through a station established to check wildlife diseases. Principle organs were taken as the carcassas were aged. Specimens were frozen until time for gamma-ray spectrometry.

Table 1

Major Items of Equipment Purchased
(Values exceeding $50)

1962

1. Willy's Station Wagon.
2. Scintillation Probes, Nuclear Chicago, DS5R.
3. Scintillation Crystal, Harshaw, XT-303, 1 3/4" well.
4. Printing timer, Nuclear Chicago C111B.
5. Lead brick, 124. -2X4X8.
6. Hot plates.
7. Sample Changer, N-C, C210 and adapters (Bl 664).

1963

8. Tech. Measurements Corp. 400-channel P.H.A., 401B.
9. " " " IBM typewriter, 530.
10. " " " " " , control, 520P.
11. " " " Resolver-integrator, 522.
12. " " " Readout switch unit.
13. " " " Tally paper tape punch.
14. " " " Tally paper tape reader.
15. " " " Preamp, DS-13.
16. Generator, 115V, 1500 W. A.C.

1964

17. Muffle Furnace, Minneapolis Honeywell Regulator Company.

1965

18. Scintillation crystal assembly, Harshaw, 4X4 solid.
19. Copymaker, Polaroid, #208.
20. Gamma-probe, Victoreen, 1 1/2 X 1 1/2 crystal.
21. 7094 Computer program, least square spectrum resolution.

RESULTS

Nearly 2000 samples of water, rocks, soils, plants, and animals (insects, reptiles, herbivores, carnivores) as well as various organs of animals, particularly deer, have been analyzed for gamma-emitting radioisotopes. These analyses were included in twelve subprojects completed during approximately 5 years of work on various problems. Each subproject is represented later in these results with an abstract and, in most cases, supporting data not published elsewhere. Three research reports have been published in journals surveyed by both periodicals Biological Abstracts and Nuclear Science Abstracts. A minimum of four manuscripts are awaiting publication.

Ten graduate and undergraduate students worked either as research assistants or as labor on various parts of the over-all project. Only two employees--principle investigator and a part-time technician--were not on degree programs, all others accomplished at least one degree by means of these investigations; 6 graduate degrees, including 4 doctorates, were supported by project funds. Although the grant was not intended nor was it operated as a training grant a lack of skilled technical assistance early in the project necessitated training personnel to accomplish both field and laboratory duties. Students were the best available research assistants and each has become an independent specialist in his particular subject.

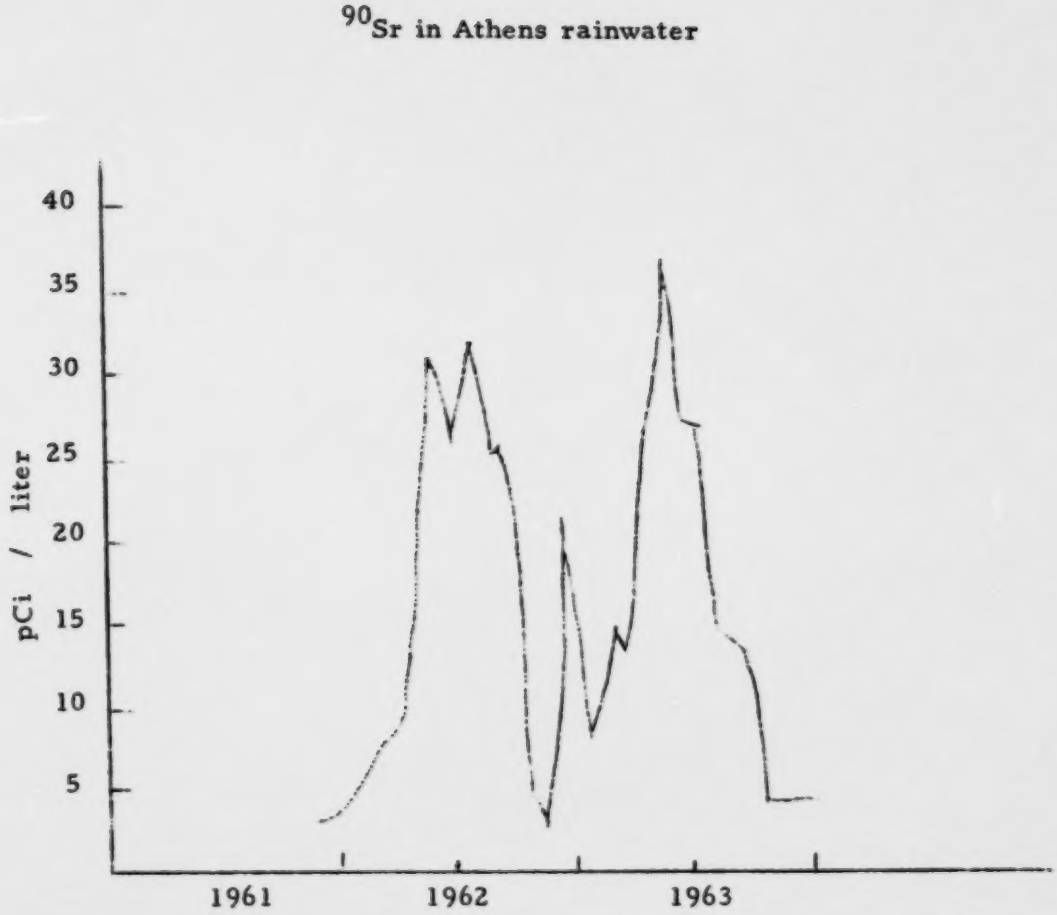
The most effective tool for the entire project, a computer program involving a linear least-square method of gamma-ray spectrum analysis, was not available until the beginning of the fourth year. Once this program was developed for our applications then all sorts of data having the desired degree of reliability began to come from a backlog of problems that awaited solution. The program verified data obtained from gamma-ray analysis before 1963. Fortunately, the program greatly increased output information on isotope concentrations in any material.

The biological material containing the most radioactivity was the lichen Parmelia conspersa (subprojects 5 and 9). Concentrations of ^{137}Cs on particular sites attained nearly 800 pCi/g dry weight in 1966 although average values were slightly lower. All evidence points toward the probability that higher concentrations will occur in Parmelia as radiocesium arrives with additional fallout. Experiments indicate that radiocesium has not leached appreciably from lichen tissues although other nuclides may do so. Concentrations of ^{90}Sr in Parmelia, on the other hand, have been comparatively small--one-tenth the ^{137}Cs concentrations orless--probably because fungi require only small amounts of calcium-like elements.

The flowering annual, Viguiera porteri a sunflower-like endemic on outcrops, contained more ^{90}Sr (125 pCi/g dry weight in 1962) than any of the other plant species assayed for this isotope. Also the moss, Polytricum commune, held relatively large amounts of ^{90}Sr (40 pCi/g dry weight) as did the perennial succulent, Talinum teretifolium (50-60 pCi/g dry weight).

Lowland populations always contained more ^{90}Sr, by a factor of 2 or 3, than their upland counterparts partly because more ^{90}Sr was funnelled over a larger surface area into lowland habitats. Viguiera always held less ^{137}Cs than the lichen Parmelia undoubtedly because the lichen incorporated radiocesium from rainwater before excess ^{137}Cs water got to Viguiera.

The following results deal with the various subprojects. Most of these sections represent independent studies, but all are related in that they are associated with background radiation throughout the Georgia Piedmont.



(Data provided by Robert A. Taft Sanitary Engineering Center)

Figure 1. Variations in ^{90}Sr in rainwater collected at Athens airport.

Table 2

Annual precipitation at selected sites related to rainfall on granitic outcrops

	Birmingham Ala.	Columbia S. C.	Atlanta Ga.	Athens Ga.
1959	51	66	42	58
1960	40	40	46	50
1961	76	45	58	59
1962	48	44	47	50
1963	55	44	55	63
1964	57	70	60	71
1965	44	52	42	41
Normal	53	46	47	48
Physiography	Mountain	Coastal Plain	Piedmont	Piedmont

Subproject 1

Title: An investigation of calcium and strontium-90 in some components of granite outcrop ecosystems of the Georgia Piedmont.

Dates: June 1961 - August 1963.

Personnel: Arthur R. Garrett Jr., grad. resch. asst.
A. B., Alabama College.

ABSTRACT

This study was designed to investigate differences in available calcium and strontium-90 among several granite outcrops of the Georgia Piedmont and to determine if these differences are reflected by the amount of these elements in an outcrop endemic species, Viguiera Porteri (A. Gray) Blake.

Determinations of calcium were made spectrophotometrically and radiometrically for strontium-90 in samples of granite, soil and Viguiera from five outcrops. Supplementary to the field collections, Viguiera was grown in the greenhouse in flats of an outcrop soil amended to four treatment levels of calcium.

Analyses of granites showed no differences in calcium among the several outcrops, except for Mount Arabia which had less than the other. Exchangeable calcium content of the soil was found to be the same on all outcrops, except Echol's Mill where it was slightly higher. No correlation between granite calcium content and soil calcium content was found.

Analyses of Viguiera showed no measureable differences in plant ash calcium content among the outcrops; likewise, no differences in uptake were observed from the greenhouse soils. No correlation between available soil calcium and plant calcium content was observed.

In general, most inter-outcrop variances were so low and the number of samples so small as to leave all hypotheses of difference between outcrops unsubstantiated and to prevent the drawing of definite conclusions regarding the effects of exchangeable soil calcium on plant calcium or the effects of the presence of calcium on strontium uptake.

The radioactivity of oxalate precipitates was about the same in granite, soil and plant samples from all outcrops except one. Gross beta radioactivity in the soil was slightly higher at Echol's Mill than on the other outcrops but the higher value was not detected in granite or plant samples. The hypothesis that available calcium has an effect on uptake of strontium-90 was not subject to evaluation due to the lack of measureable variation in either calcium or strontium-90 between sites.

Preliminary measurements showed considerable seasonal variation in exchangeable calcium on one outcrop.

Reports: Garrett, A. R., Jr. 1963. M.S. thesis. Department of Botany, University of Georgia, Athens.

Table 3

Mean calcium content of outcrop ecosystem components

Site	Total Ca content of granite (ppm)	Exchangeable Ca content of soil (ppm)	Total Ca content of Plant ash (ppm)
Echol's Mill	200	33.5	41.5
Anglin's Farm	260	4.0	33.6
Rockdale County	212	2.6	42.5
Greensboro	260	1.1	50.6
Mount Arabia	100	7.6	27.1

Table 4 Subj. 1

Variability in samples of exchangeable soil Ca (ppm) within two outcrops

Site replications	Sample a	Sample b	Pit mean
	Echol's Mill		
Pit a	34	32	33.0
Pit b	1	2	1.5
Pit c	78	76	77.0
Pit d	12	11	11.5
Site mean	-	-	30.8
	Mount Arabia		
Pit a	12	10	11.0
Pit b	2	4	3.0
Pit c	2	2	2.0
Pit d	14	15	14.5
Site mean	-	-	7.6

Table 5

Mean exchangeable calcium contents of spring and autumn soil samples

Pit number	Spring (ppm)	Autumn (ppm)	% change during growing season
a	190	33.0	83
b	2.0	1.5	25
c	115	77.0	33
d	32.5	22.0	32

Table 6

Mean count rate of oxalate precipitate of material from each outcrop

Site	Granite (counts per minute per gm)[1]	Soil (counts per minute per 100 gms)[1]	Plant (counts per minute per gm)[2]
Echol's Mill	8.4	119	124
Anglin's Farm	8.9	38	212
Rockdale County	10.0	20	292
Greensboro	9.0	44	294
Mount Arabia	9.4	46	457

[1]Based on 1000 counts

[2]Based on 2000 counts

Table 7

Mean exchangeable calcium content of amended soil* compared with calcium content of Viguiera ash

Soil treatment	Soil (ppm)	Viguiera ash (ppm/10³)
Untreated	40.5	156
Lowest treatment	1260	155
Intermediate treatment	2930	164
Highest treatment	4900	160

*Soil to which calcium treatments were added

Subproject 2

Title: Radioactive fallout and vegetation.

Dates: November 1, 1961 - January 1963.

Personnel: G. L. Plummer,
Technicians: J. D. Blake; J. B. Moncrief, Jr.

ABSTRACT

Various plant species in different habitats have been assayed by gamma spectrometry to determine the relative amounts of certain fallout radionuclides that are concurrent with each species. Fission products contaminate vegetation by direct deposition from airborne particles and by the physiological processes of bioaccumulation.

The net gamma spectrum differs for each species and for each micro-habitat within a mutual area. The abundance of one radionuclide may vary as much as 30 times from one plant to another. A radionuclide in conjunction with a plant species varies in abundance with the season. Fallout fission products are transported by runoff rain water from one micro-habitat to another, and bioaccumulation is indicative of the input or output in the respective habitats.

Reports: Plummer, G. L. 1963. Assoc. Southeastern Biol. Bull. 10:36.

Table 8

Subj. 2

Strontium-90 and Plants (pCi/gram dry weight)

Species	Winter '61-'62	Spring 1962	Summer 1962	Autumn 1962
Parmelia conspersa	1.76	4.52 7.85 14.20	1.84 (11.30 in '63)	2.80 6.80
Cladonia sp.	3.20 1.33 4.90	-	5.45 7.40	4.50 11.75 6.38 5.47
Polytricum commune	-	13.50	-	18.3 21.9 20.6 25.6 48.5 16.7
Hypericum gentianoides	23.6	-	-	22.6
Senecio tomentosus	23.6	-	-	-
Panicum sp.	-	-	-	15.3
Vaccinium arborium	-	-	-	17.6
Talinum teretifolium	-	55.5	-	-
Viguiera porteri	9.55 23.9 31.3	-	20.8 125.0 26.6 47.2	34.2 up[1] 103.0 low 60.5 up & low 57.0
Andropogon virginicus	-	4.20 3.81	3.80 2.20 up 4.08 low 3.80	-
Juniperus virginiana (twigs)	5.85	-	3.58 up 11.2 low (10.1 in '63)	
Quercus georgiana (leaves)	-	-	13.5	8.60

[1] Upland and lowland habitats respectively

Fig. 2. Gamma-ray spectrum and location of several radioisotopes in fallout.

Fig. 3. Typical gamma-ray spectrum of fresh ash from Parmelia conspersa (lichen) during 1963 showing considerable amounts of ^{137}Cs, $^{95}ZrNb$, and ^{54}Mn under one large peak. Horizonal axis shows 0-200 mev in 200 channels; vertical axis indicates amount of radioactivity in each channel.

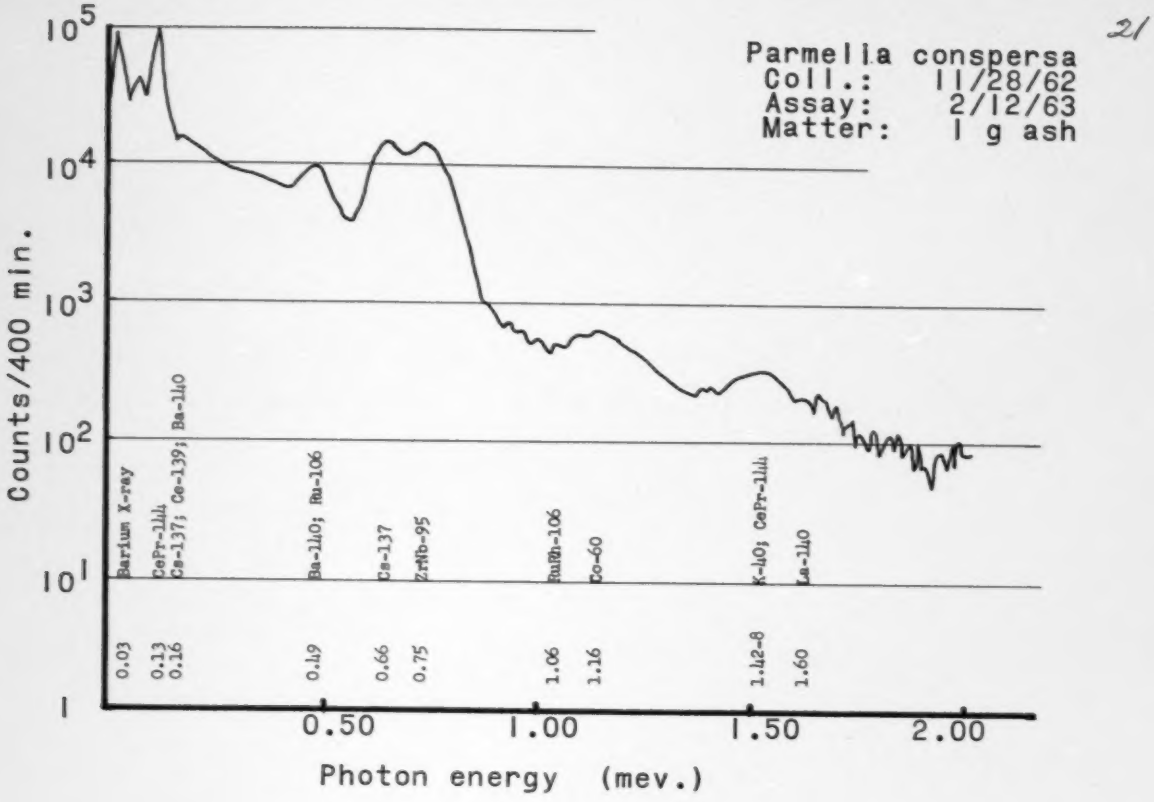
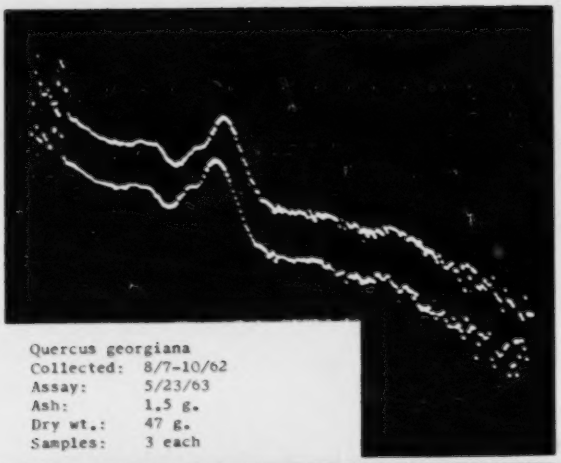
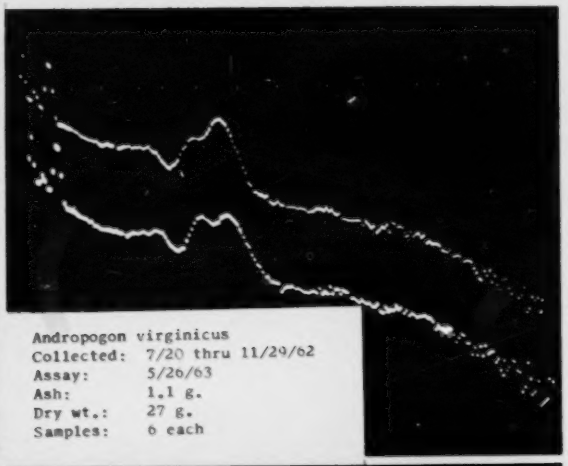

Parmelia conspersa
Coll.: 11/28/62
Assay: 2/12/63
Matter: 1 g ash
Counts/400 min.
10^5
10^4
10^3
10^2
10^1
1
Barium X-ray
CePr-144
Ce-137; Ce-139; Ba-140
Ba-140; Ru-106
Cs-137
ZrNb-95
RuRh-106
Co-60
K-40; CePr-144
La-140
0.03
0.13
0.16
0.49
0.66
0.75
1.06
1.16
1.42-8
1.60
0.50
1.00
1.50
2.00
Photon energy (mev.)

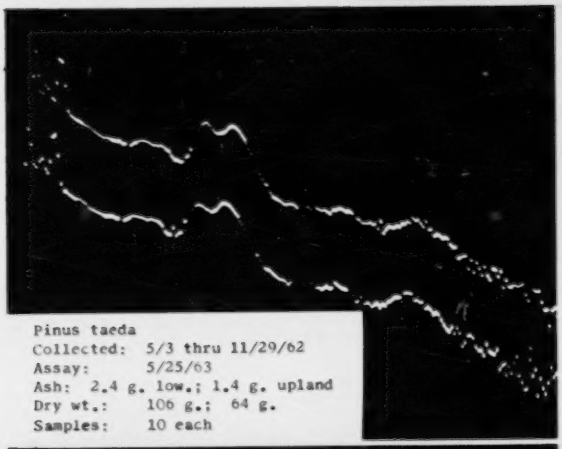
Fig. 4. Comparison of gamma-ray spectra from upland (top-most curve) and lowland populations. Superimposition shows variability in kinds of nuclides present and relative amounts of each.



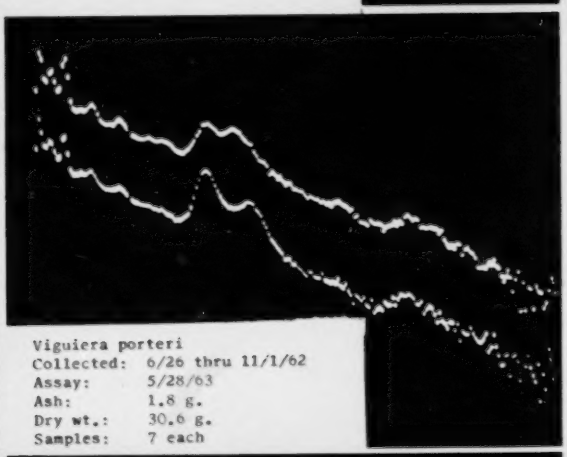
Quercus georgiana
Collected: 8/7-10/62
Assay: 5/23/63
Ash: 1.5 g.
Dry wt.: 47 g.
Samples: 3 each



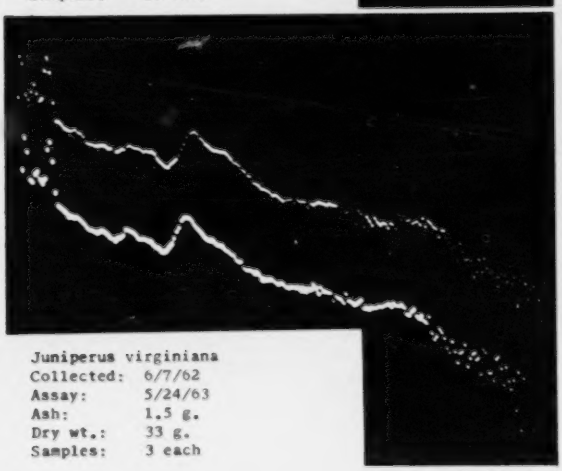
Andropogon virginicus
Collected: 7/20 thru 11/29/62
Assay: 5/26/63
Ash: 1.1 g.
Dry wt.: 27 g.
Samples: 6 each



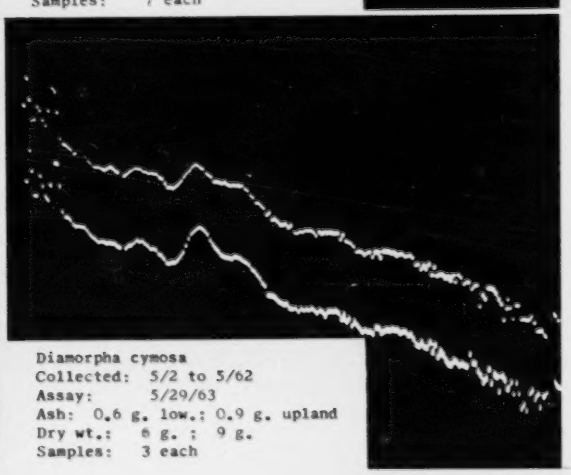
Pinus taeda
Collected: 5/3 thru 11/29/62
Assay: 5/25/63
Ash: 2.4 g. low.; 1.4 g. upland
Dry wt.: 106 g.; 64 g.
Samples: 10 each



Viguiera porteri
Collected: 6/26 thru 11/1/62
Assay: 5/28/63
Ash: 1.8 g.
Dry wt.: 30.6 g.
Samples: 7 each



Juniperus virginiana
Collected: 6/7/62
Assay: 5/24/63
Ash: 1.5 g.
Dry wt.: 33 g.
Samples: 3 each



Diamorpha cymosa
Collected: 5/2 to 5/62
Assay: 5/29/63
Ash: 0.6 g. low.; 0.9 g. upland
Dry wt.: 6 g. ; 9 g.
Samples: 3 each

Subproject 3

Title: Lichen growth on granitic flatrocks in Georgia.

Dates: August 1962 - August 1963.

Personnel: James B. Moncrief, Jr.
(NSF, High School Research Participant, summer 1962, G-8121).
Project technician, June1963 - September 1965.

ABSTRACT

Growth rates of lichens were measured monthy for one year in order to: (a) determine at what time during the year growth was most rapid, (b) estimate annual growth increments attained by several lichens, and (c) evaluate effects of various fertilizers on lichen growth.

Although Dermatocarpon fluviatile in the field grew most, with a radial increment of 2.3 mm during the year, Cladonia caroliniana, which grew the least with 1.1 mm, had a much better percentage increase; and no records were made of upright expansion in this fruticose species.

Among the fertilizer treatments, potash apparently stimulated lichen growth more consistently than ammonium nitrate, calcium phosphate, and a combination of the three.

All growth increments at the end of the study were statistically significant. The finding, combined with the other data obtained, suggests that (a) species of Cladonia grow more rapidly than Parmelia conspersa and Dermatocarpon fluviatile, and that (b) small specimens increase proportionally more than large specimens. Since all of the cladonias measured were small specimens, however, it is not yet clear whether the differences in growth rates observed were species-specific.

Observations indicate a distinct value in potash, and probably ammonium nitrate, for lichen growth. The fact that various fertilizers produced a small growth response in all species is an interesting outcome of these studies. At least, the results give some encouragement about lichen sensitivities to particular nutrients. Thus, a basis has been established whereby future studies have certain points of departure. (See subproject number 9.)

Reports: Plummer, G. L. and J. B. Moncrief, Jr. 1964. Bull. Georgia Acad. Sci. 22:58-64.

Subproject 4

Title: Movement and distribution of radionuclides within a granitic outcrop ecosystem.

Dates: June 1964 - June 1965.

Personnel: Frank A. Helseth, grad. resch. asst.
B. S., Appalachain State Teachers College.

ABSTRACT

Gamma-ray spectrometric analyses were made on soil and plant components from upland and lowland soil-pit communities on a granitic outcrop in Greene County, Georgia. This area is located in a section where the fallout compared to other sections of the United States has been relatively high.

The natural-occurring radionuclide, thorium, was uniformly distributed in the upland and lowland soil-pits. Less K-40 was held in the topsoil than in the subsoil. K-40 in the topsoil was subject to uptake and accumulation by the lowland water-outlet than at the upland water-inlet which suggests that potassium moved from the upland areas through the lowland areas.

The topsoil contained more fallout radionuclides (Ce-144, Ru-106, Cs-137, Mn-54, Zr-95) than the subsoils. Upland soils contained more fallout radioactivity than lowland soils. Soil at the lowland water-inlet contained three times more fallout radioactivity than soil at the upland water-inlet. This concentration phenomena has been associated with the larger drainage area which channeled large quantities of water into the lowland areas.

Generally, plants in lowland soil-pits contained more radioactivity than those in upland soil-pits. The aster Viguiera porteri contained more Mn-54 than did the lichen Cladonia caroliniana. The differential accumulation of Mn-54 was associated with the increased photosynthetic activity of Viguiera. The lowland Cladonia contained the largest concentration of fallout radionuclides of any component sampled. The prostrate growth characteristic associated with the large surface area of the Cladonia and its ability to absorb water rapidly facilitated the accumulation of radionuclides from the run-off waters during the periodic flooding experienced by lowland areas.

Reports: Helseth, F. A. and G. L. Plummer. 1965. Assoc. Southeastern Biol. Bull. 12:46.
Helseth, F. A. 1965. M.S. thesis. Department of Botany. University of Georgia, Athens.

Table 9

Description of the area of study on the Greensboro outcrop

Pit	Elevation[1]	Area[2]	Drainage Area[2]
1.0	111.93	5.76	31.94
1.1 (inlet)	110.01	22.53	232.83
(outlet)	108.69		
2.0	109.69	22.53	232.83
2.1	107.58	6.19	391.01
3.0	109.64	6.72	25.84
3.1	109.18	5.21	45.94
4.0	106.48	8.16	49.99
4.1	102.19	19.46	341.47
5.0	101.68	6.14	81.72
5.1	100.00	5.29	127.74

[1]Values reported in feet

[2]Values reported in square meters

Table 10 Subj. 4

Upland and Lowland soil analysis for available P, K, Ca, Mg, Mn

	Elements (ppm)				
	P	K	Ca	Mg	Mn
UPLAND:					
Top	2.5	7.5	250.0	15.63	1.5
Bottom	2.5	2.5	125.0	11.88	2.3
Inlet	5.0	7.5	562.5	18.75	2.0
Outlet	2.5	5.0	437.5	18.75	2.5
LOWLAND:					
Top	5.0	7.5	250.0	18.75	2.0
Bottom	5.0	2.5	125.0	12.50	1.8
Inlet	5.0	10.0	437.5	18.75	2.5
Outlet	2.5	5.0	437.5	18.75	2.5

Fig. 5. Diagrammatic scheme of the distribution of radioactivity in upland and lowland soil-pits.

DISTRIBUTION OF THORIUM AND K-40 IN UPLAND AND LOWLAND SOIL

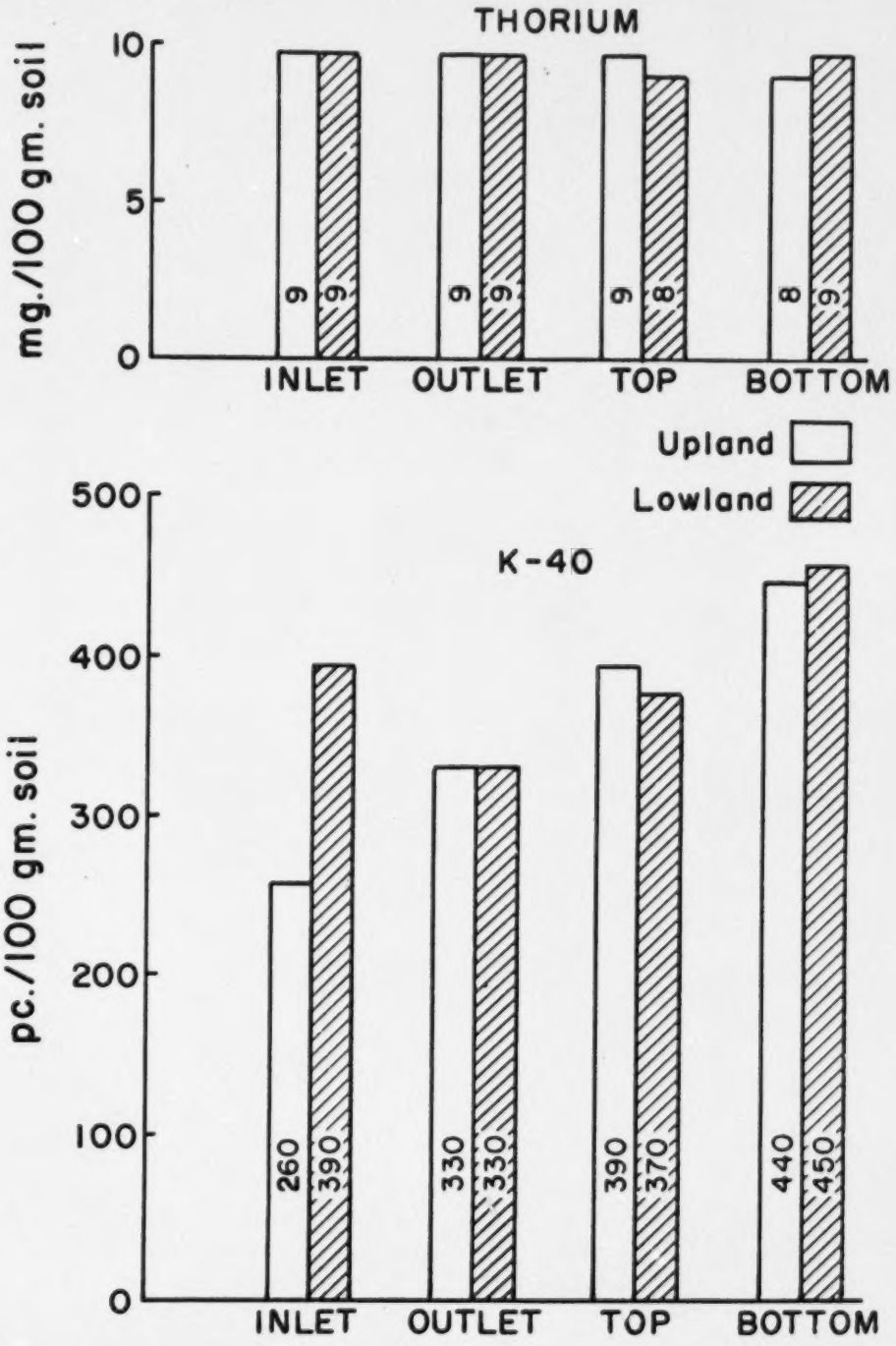
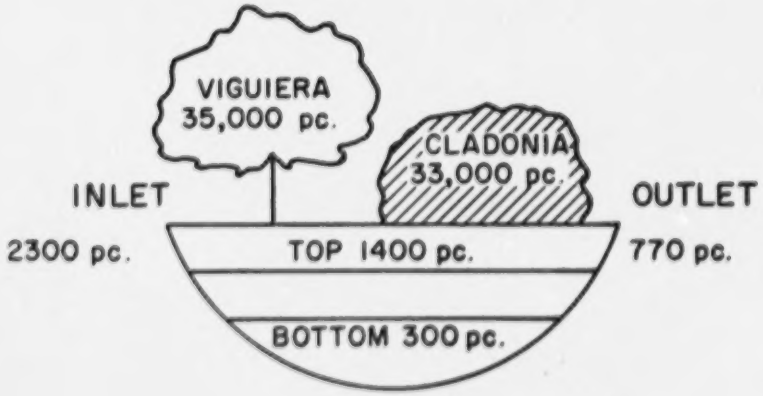
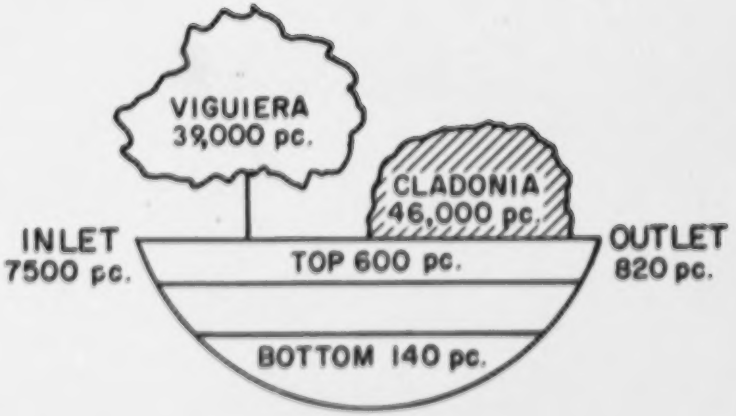


Fig. 6. Distribution of Thorium and K-40 in upland and lowland soil.

DIAGRAMMATIC SCHEME OF THE DISTRIBUTION OF RADIOACTIVITY IN UPLAND AND LOWLAND SOIL-PITS



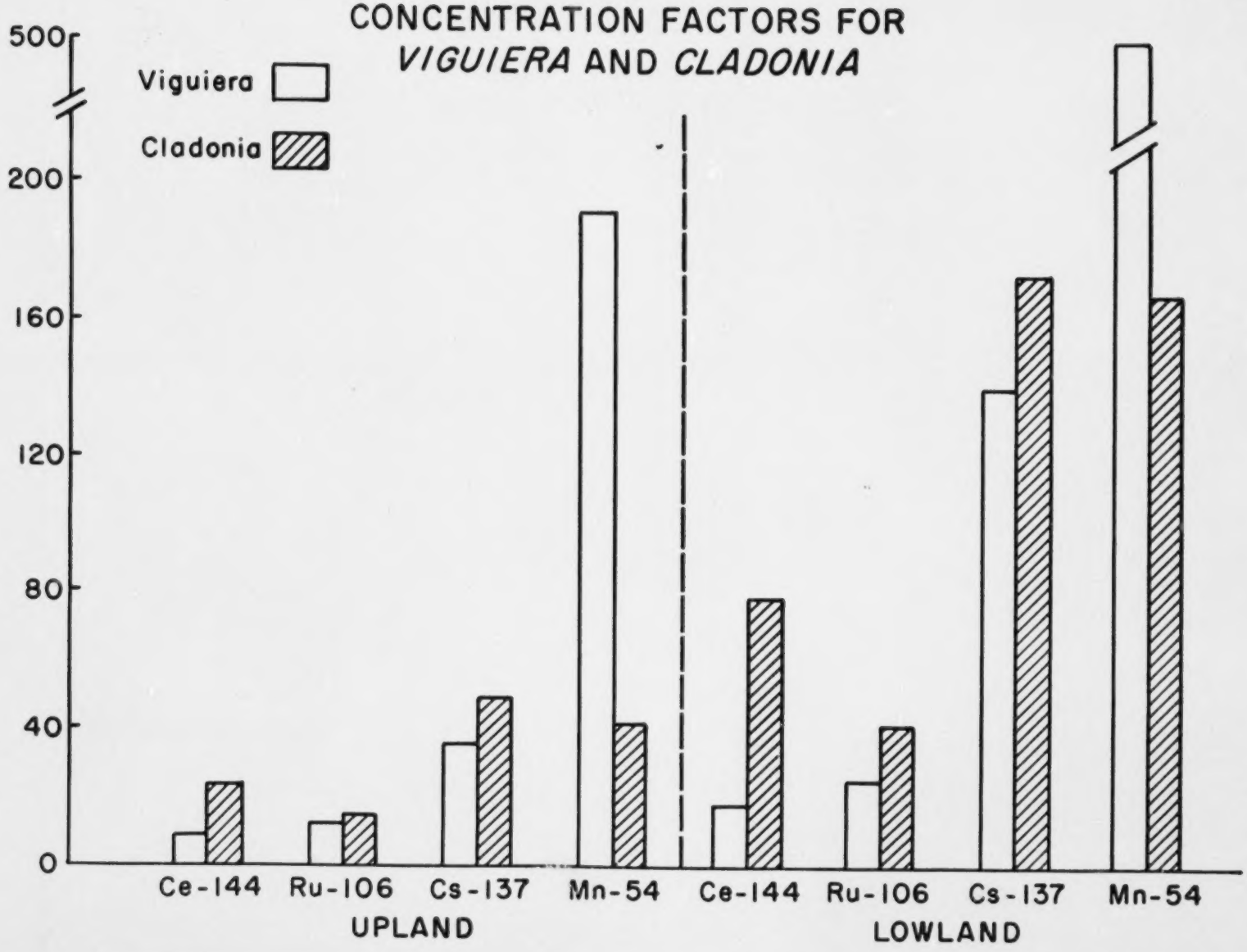
UPLAND
73,000 pc.



LOWLAND
94,000 pc.

28

Fig. 7. Concentration factors for Viguiera and Cladonia.


CONCENTRATION FACTORS FOR
VIGUIERA AND CLADONIA
Viguiera
Cladonia
500
200
160
120
80
40
0
Ce-144
Ru-106
Cs-137
Mn-54
Ce-144
Ru-106
Cs-137
Mn-54
UPLAND
LOWLAND

28c

Subproject 5

Title: Movement and distribution of radionuclides on granitic outcrops.

Dates: January 1963 - May 1965.

Personnel: G. L. Plummer,
Technicians: J. Donald Blake; J. B. Moncrief, Jr.;
T. M. Pullen, Jr.; F. M. Veal.

ABSTRACT

From 1962 through 1964, radioactive fallout in parts of the southeastern U.S. has been detected in greater quantity than in many other places of the country. Flatrock ecosystems in Georgia retain very little rainwater; most run-off water flows through a series of communities which filter and retain fallout radionuclides. When fallout-bearing water flowed over barren rocks, lowland communities always held more radionuclides than upland communities. Usually, however, upland communities removed particular isotopes from surplus run-off water.

Parmelia conspersa, an "upland" lichen, had higher concentrations of ^{137}Cs (up to 300 pCi/g dry wt.) than any other plant in 1964. Viguiera porteri, an aster, held the largest concentrations of ^{90}Sr (up to 125 pCi/g). Concentrations of fallout were higher in upland Juniperus virginiana than in lowland populations, although the spectrum of isotopes at both sites was similar.

Even though each granitic outcrop as a whole is a relatively simple ecological system, it consists of smaller systems wherein the dynamics of radioisotope movements and bioaccumulation can be understood only in terms of intimate familiarity with each little system contributing to the whole. Maximum concentration levels for any component have not been ascertained; nevertheless, accumulation of isotopes within Parmelia and Viguiera may well indicate the extent to which fallout has become an environmental "contaminant" in the Southeast.

Reports: Plummer, G. L. 1963. Movement of radionuclides through granitic outcrop ecosystems. Bull. Ecol. Soc. Amer. 44:75.
Plummer, G. L. 1964. Radioactive fallout in the Georgia Piedmont. Bull. Georgia Acad. Sci. 22:2.
Plummer, G. L. and F. A. Helseth. 1965. (In the Proc. Hanford Symposium, Radiation and Terrestrial Ecosystems, held in Washington, May 1965) Health Physics 11:1423-1428.

Table 11

Fallout concentrations in composite plant materials during early summer, 1963

Granite outcrop plants	Cs-137		Mn-54	
	High sites	Low sites	High sites	Low sites
	(picocuries/kilogram dry weight)			
Pinus taeda (leaves)	8,050 ± 15%	5,350	17,000 ± 15%	33,400
Viguiera porteri (annual aster)	17,500	32,200	128,000	163,000
Talinum teretifolium (perennial herb)	26,500	14,300	167,000	85,000
Polytricum commune (moss)	31,200	45,200	67,600	96,600
Parmelia conspersa (lichen)	177,000	1	170,000	1

1 No population on low sites

Subproject 6

Title: ^{137}Cs and ^{54}Mn from fallout in trees on granitic outcrops.

Dates: May 1962 - March 1964.

Personnel: G. L. Plummer,
Technicians: J. D. Blake; T. M. Pullen, Jr.

ABSTRACT

Concentrations of certain radioisotopes in outcrop trees exceeded concentrations previously reported in other areas. Topographic features of the habitats are partly responsible for "high" concentrations, but biological characteristics of the outcrop species are equally important. Cs-137 and Mn-54 concentrations in trunk-wood varied with annual-increment groups, which indicated a) differential accumulation of isotopes, b) differences in radial translocations, c) translocations through wood-ray cells were probably more active than translocations by radial diffusion, and d) Mn-54 was accumulated better than Cs-137. Mn-54 was found in wood laid down prior to 1940 although that isotope first appeared in fallout in 1956, and moreso in 1962. Pine trees are known to be relatively sensitive to ionizing radiations; thus, pines with unusually high radionuclide concentrations, and under some sort of "stressed" conditions, could respond to an abundance of fallout radioactivity providing an appropriate combination of circumstances existed on the outcrops.

Reports: Plummer, G. L. 1966. Manuscript.
Department of Botany, University of Georgia, Athens.

Fig. 8. Comparison of gamma-ray spectra from various parts of one upland pine tree. In "C" the 1963 twigs held more ^{137}Cs than ^{54}Mn whereas in 1960 twigs, "E", more ^{54}Mn occurred than ^{137}Cs.

PINUS IN 1963

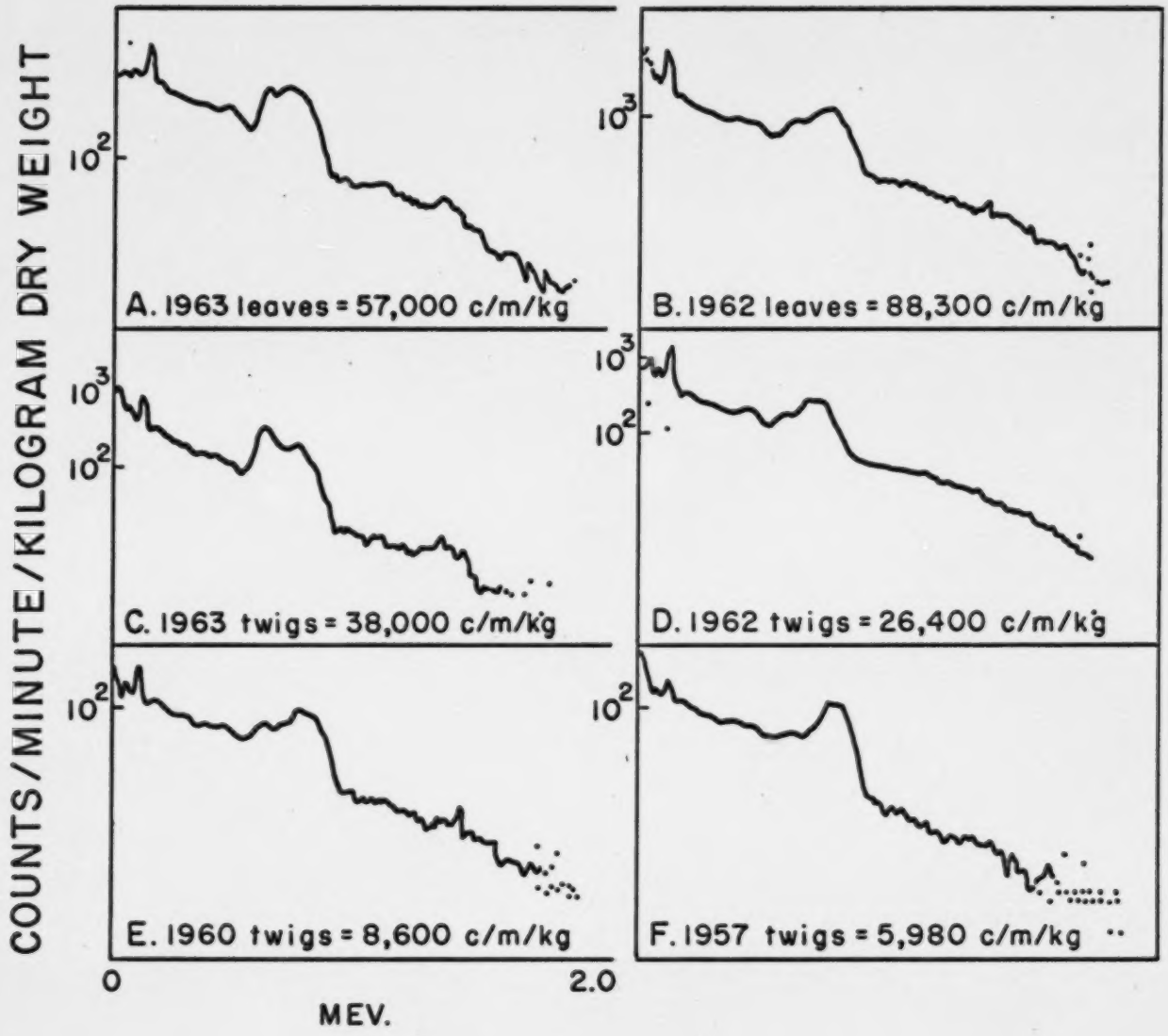
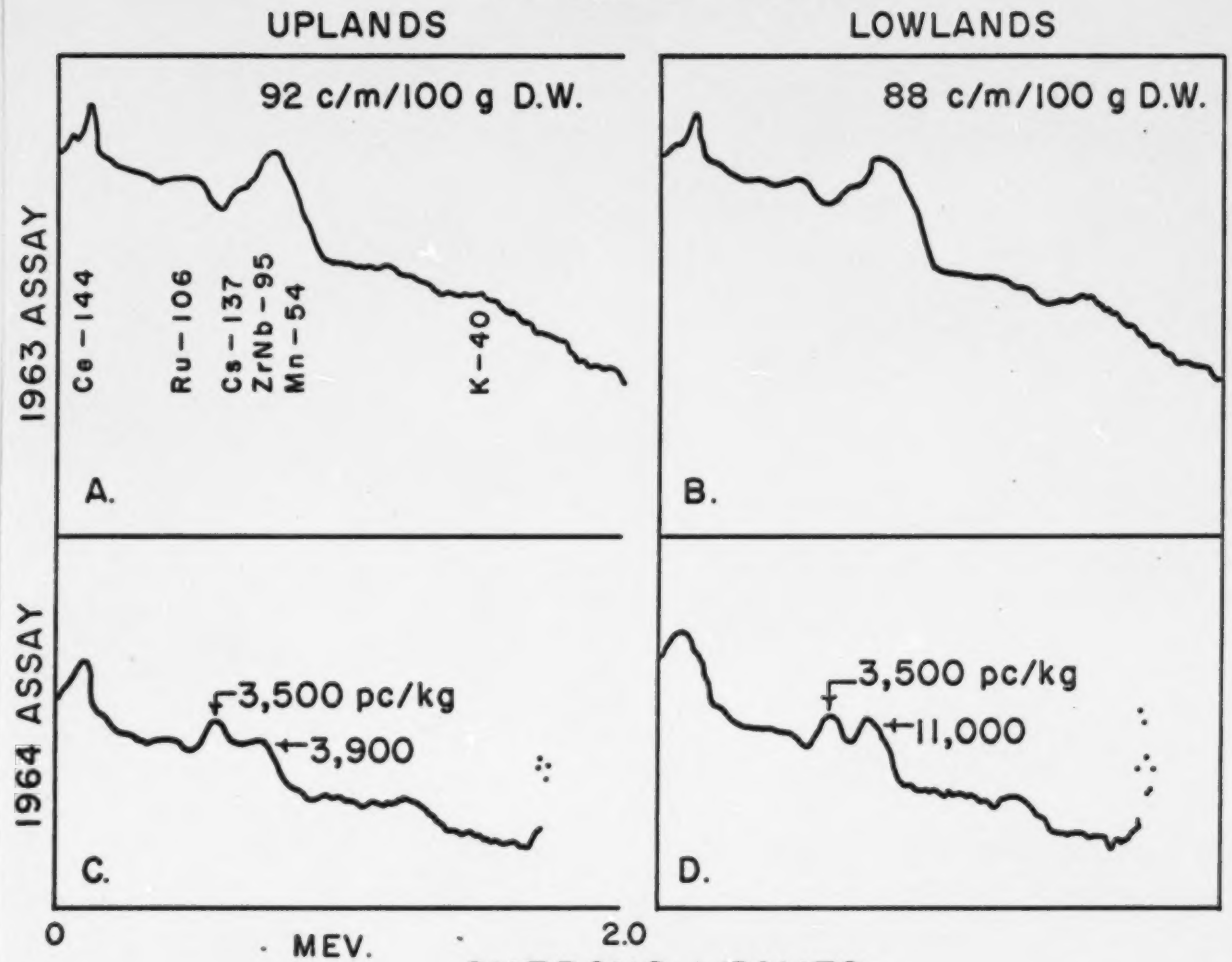


Fig. 9. Upland and lowland pines are compared in "A" and "B". In "C" and "D" the above samples were counted again, but one year later; ^{137}Cs was 3500 pCi, ^{54}Mn was 3900 and 11,000 pCi respectively. Lowland oaks "F" held more ^{137}Cs and ^{54}Mn than upland oaks.

PINUS LEAVES
(1963 COLLECTION)



QUERCUS LEAVES
(1963 COLLECTION)

Fig. 10. More ^{54}Mn occurred in 1950-1953 pine wood than in any other increment group; 320 pCi of ^{137}Cs occurred in heartwood. Right column shows gamma-ray assays on same material one year after those in left column.

PINUS WOOD
(1963 COLLECTION)

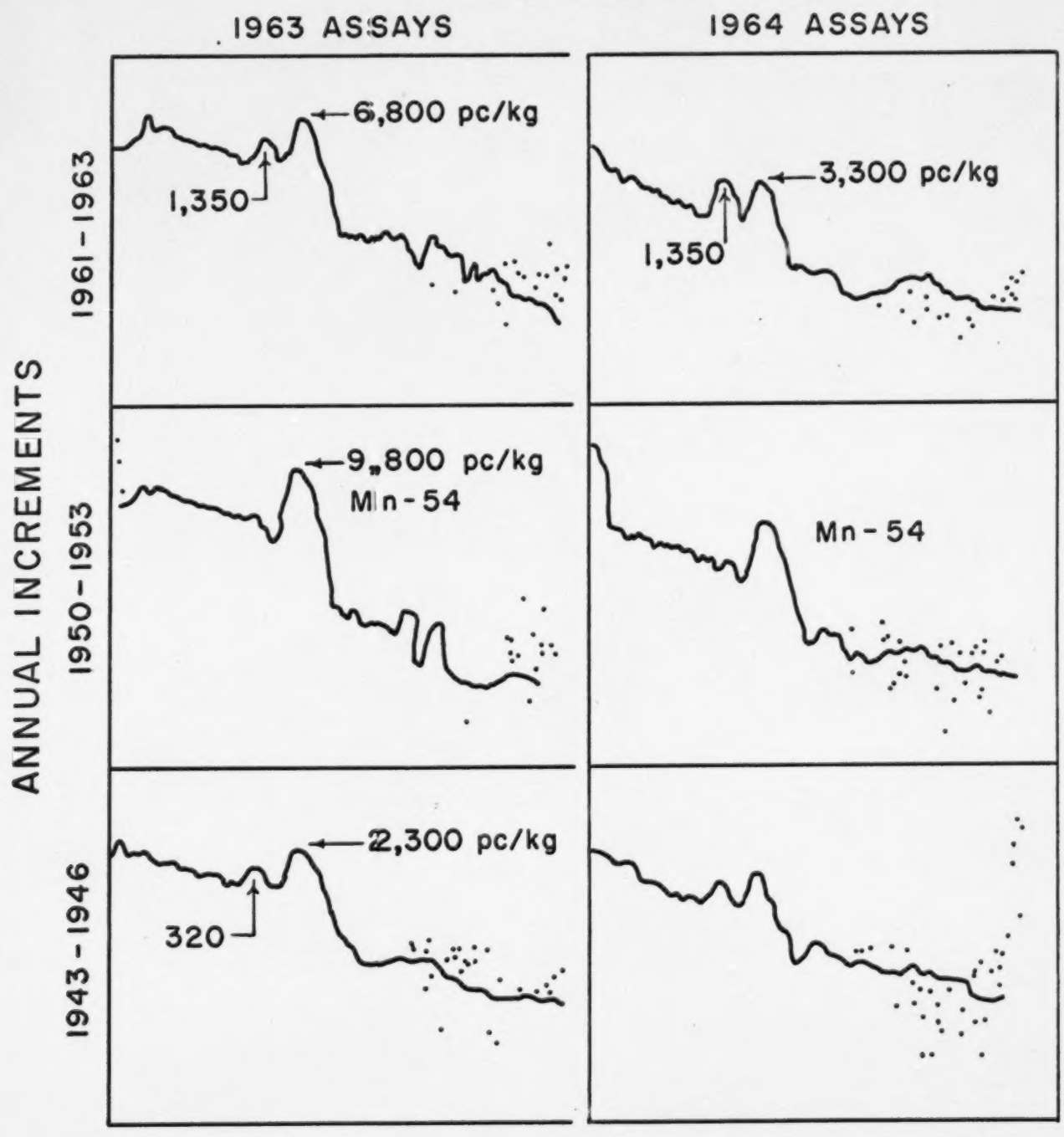
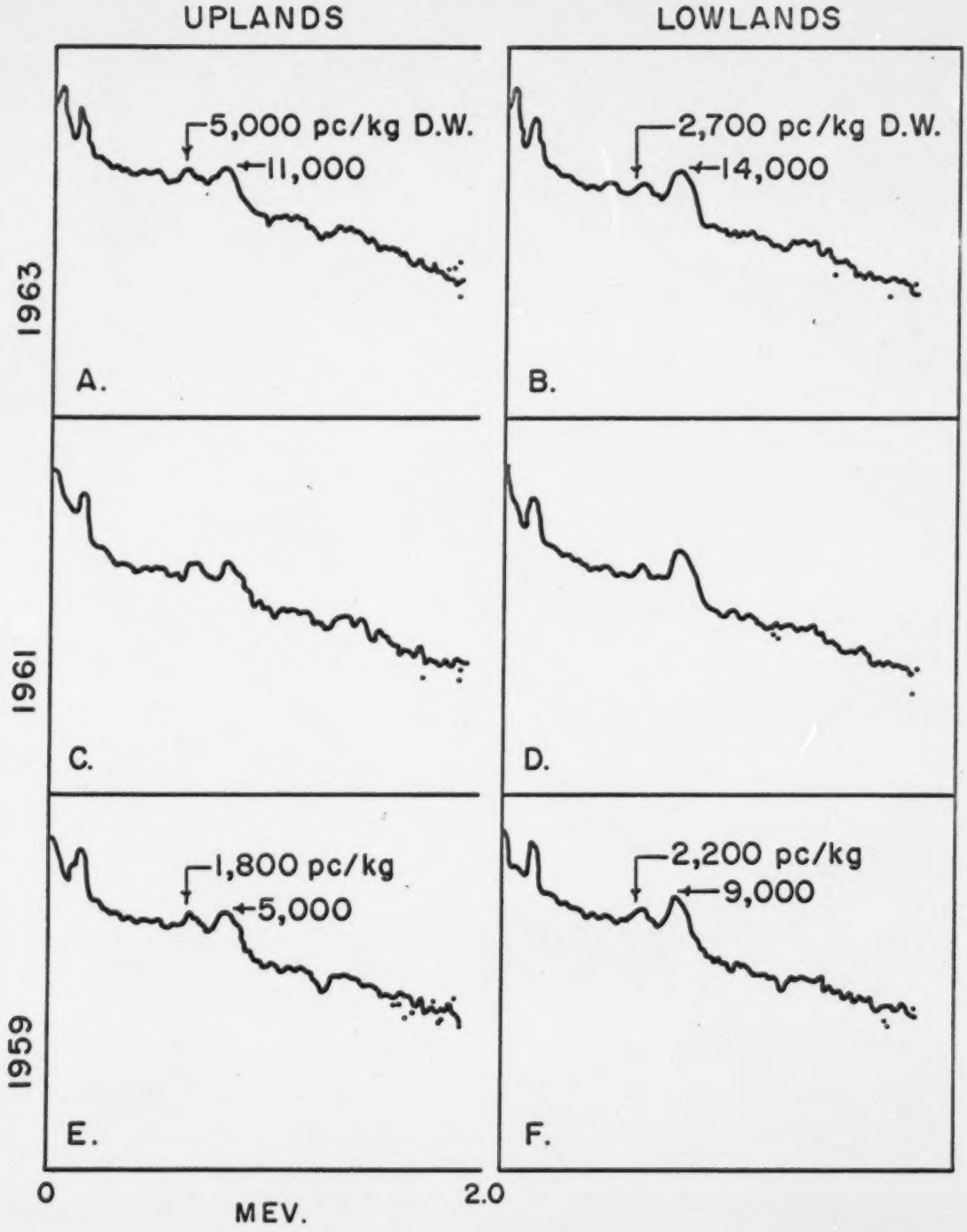


Fig. 11. Lowland oak twigs held 4-5 times more ^{54}Mn than ^{137}Cs.

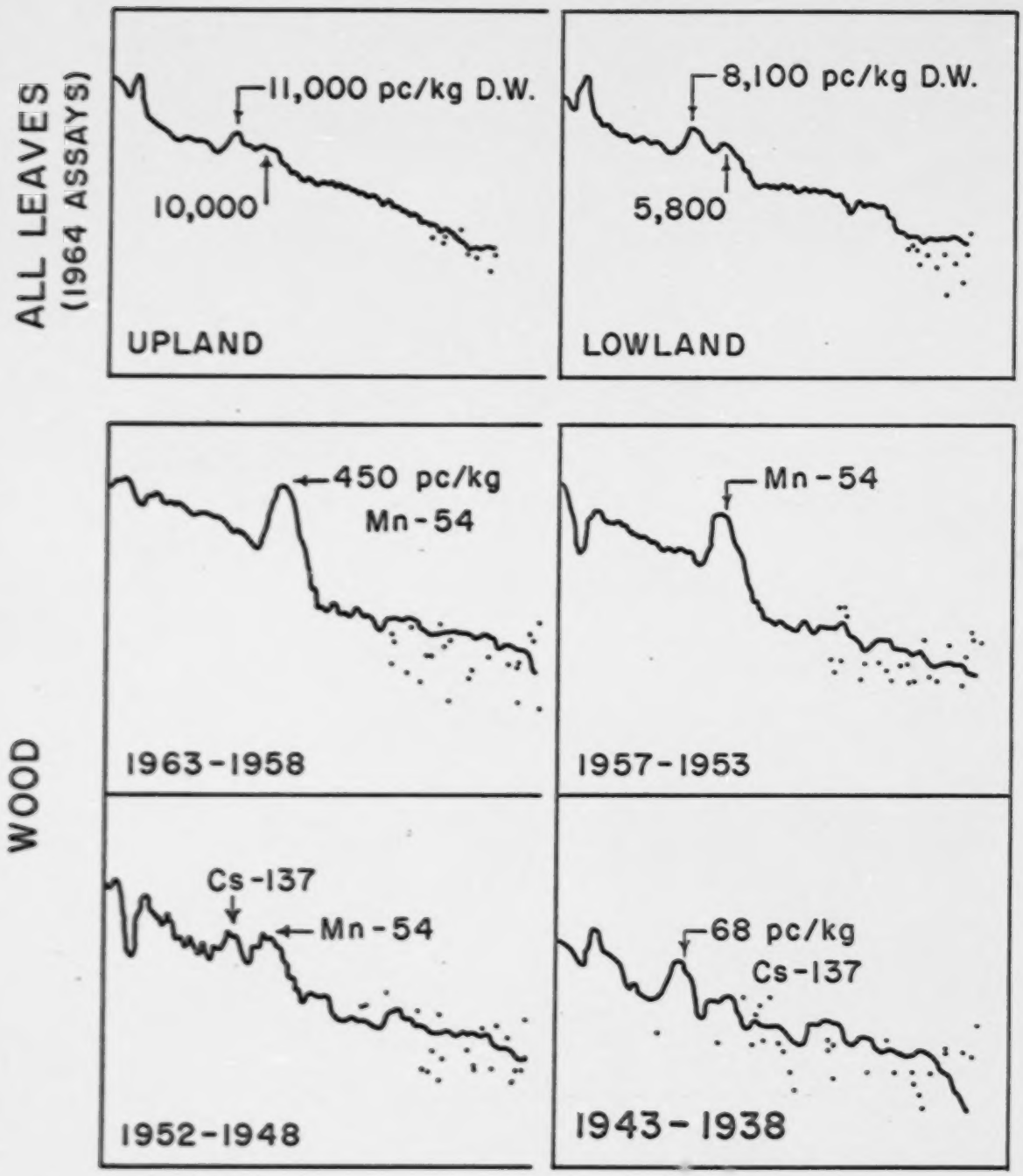
QUERCUS TWIGS
(1963 COLLECTION)



37c

Fig. 12. Leaves from upland Juniperus held more ^{137}Cs (11,000 pCi) and ^{54}Mn (10,000 pCi) than lowland junipers. Sapwood held more ^{54}Mn than ^{137}Cs during 1963 through 1958, but 1938 heartwood held more ^{137}Cs (68 pCi) than ^{54}Mn (trace).

JUNIPERUS
(1964 COLLECTION)



Subproject 7

Title: Radioisotopes in tree species inhabiting granitic outcrops and woodlands.

Dates: March 1964 - June 1966.

Personnel: J. Daniel Pittillo, Grad. Resch. Asst.
M.S., Univ. Kentucky.

ABSTRACT

Soil and tree constituents of three contrasting habitats were sampled and analyzed for chemical nutrients and radioisotopes to evaluate bioaccumulation characteristics within the respective habitats. Radionuclides were in greatest abundance in soils of lowland outcrops, followed by highland-outcrop soils. Outcrop soils that had the most organic matter also had highest cation-exchange capacity in terms of total measured milliequivalents. Trees growing in these higher-nutrient outcrop soils contained smaller amounts of each radioisotope, regardless of higher or lower radioisotopic concentrations in the soils. Woodland soils contained less organic matter percentages, more nutrients and less of each radioisotope compared to the shallower and more poorly developed outcrop soils. Woodland trees contained smaller quantities of a given radioisotope and often had greater amounts of cations than outcrop trees. Oak trees accumulated the most, pines the least and junipers intermediate amounts of cations and of each radioisotope. Oaks and pines in lowland habitats concentrated more of each radioisotope but junipers in highland habitats concentrated more of each radioisotope than lowland or woodland junipers.

Concentrations of radioisotopes in plant parts were highest in leaves, followed by twigs, bark (or phloem), sapwood and heartwood respectively. Some isotopes, Cs-137, Ce-144, Ru-106, Zr-95 and Zn-65, were associated primarily with external parts such as leaves, twigs and cork, whereas Mn-54 was associated mainly with internal parts such as phloem and wood. Structures having live tissues (leaves, twigs, phloem and sapwood) had higher radioisotopic concentrations than those composed of dead tissues (cork and heartwood). Cesium-137 concentrations in pines were higher in cones and phloem, where foods are stored, than in wood or cork. Relative to other parts, Mn-54 concentrations were higher in leaves and bark (or phloem), where live tissues predominate. Radioisotopic concentrations in the wood decreased sharply inward past the sapwood, except Cs-137 increased slightly in pine heartwood. Thus, greater amounts of radionuclides in trees are functions of: 1) increased amounts of radionuclides in the soil, 2) decreased abundance of available soil nutrients and 3) plant species differences in morphological form (rough surfaces), nutrient storage and nutrient storage and nutrient contribution to the soils from the foliage and litter of each species.

Reports: Pittillo, J. D. and G. L. Plummer. 1965. Bioaccumulation of fallout radionuclides in Juniperus virginianus. Assoc. Southeastern Biol. Bull. 12:49.

Pittillo, J. D. and G. L. Plummer. 1965. Accumulation of radioisotopes in Juniperus virginiana L. Bull. Georgia Acad. Sci. 23:95-104.

Pittillo, J. D., G. L. Plummer, and H. F. Perkins. 1966 Accumulation of radioisotopes within Pinus taeda, Juniperus virginiana and Quercus georgiana in two ecosystems. Assoc. Southeastern Biol. Bull. 13:44.

Pittillo, J. D. 1966. Ph.D. dissertation. Department of Botany, University of Georgia, Athens.

Plummer, G. L. and J. D. Pittillo. 1966. Fallout in outcrop trees. Manuscript (submitted to Rad. Health Data and Reports). Department of Botany, University of Georgia, Athens.

Table 12 Subj. 7

Radioactivity (pCi/g. dry wt.) in Quercus georgiana[1]

Plant Part (years)	Habitat	Cs-137	Mn-54	Ce-144	Ru-106
Leaves	Highland	4.5	18.0	8.5	5.1
	Lowland	8.7	74.0	12.0	12.0
	Woodlands	2.5	2.6	9.9	4.2
Twigs	Highland	2.8	11.0	4.5	3.6
	Lowland	5.5	49.0	6.4	9.3
	Woodlands	1.7	5.0	6.1	3.0
Bark	Highland	2.3	8.5	4.4	2.8
	Lowland	2.2	20.0	6.7	7.3
	Woodlands	1.9	1.2	3.9	2.8
Wood (58-64)	Highland	1.10	2.900	0.540	0.630
	Lowland	1.70	6.800	1.000	1.200
	Woodlands	0.29	0.018	0.052	0.021
Wood (53-58)	Highland	0.78	2.700	0.270	0.460
	Lowland	1.33	6.200	0.670	1.000
	Woodlands	0.21	Trace	0.022	0.000
Wood (48-53)	Highland	0.57	1.400	0.160	0.230
	Lowland	1.40	2.000	0.240	0.380
	Woodlands	0.10	0.015	0.015	0.011
Wood (43-48)	Highland	0.49	1.100	0.100	0.120
	Lowland	0.82	0.780	0.130	0.210
	Woodlands	0.08	0.018	0.017	0.012
Wood (38-43)	Highland	0.34	0.240	0.024	0.097
	Lowland	0.25	0.000	0.003	0.023
	Woodlands	0.09	0.000	0.008	0.058

[1]Data averaged from 5 samples representing 11-168 grams dry material/sample

Table 12 Subj. 7

Radioactivity in Quercus georgiana (cont.)

Plant Part (years)	Habitat	Sb-125	Zr-95	Zn-65	K-40
Leaves	Highland	1.3	0.11	0.14	1.1
	Lowland	0.7	0.00	0.01	1.4
	Woodlands	1.3	0.08	0.37	1.2
Twigs	Highland	0.28	0.02	0.25	1.0
	Lowland	0.26	0.00	0.21	1.1
	Woodlands	0.27	0.04	0.3)	0.8
Bark	Highland	0.66	0.16	0.3(	0.8
	Lowland	1.30	0.33	0.2(	1.2
	Woodlands	0.31	0.08	0.12	0.1
Wood (58-64)	Highland	0.260	0.080	0.046	0.39
	Lowland	0.250	0.140	0.020	0.33
	Woodlands	0.023	Trace	0.000	0.31
Wood (53-58)	Highland	0.046	0.019	0.021	0.23
	Lowland	0.120	0.036	0.047	0.32
	Woodlands	0.011	0.002	0.025	0.25
Wood (48-53)	Highland	0.030	0.025	0.008	0.20
	Lowland	0.037	0.037	0.023	0.24
	Woodlands	0.005	0.003	0.015	0.16
Wood (43-48)	Highland	0.015	0.019	0.038	0.22
	Lowland	0.017	0.021	0.022	0.14
	Woodlands	0.008	0.008	0.018	0.15
Wood (38-43)	Highland	0.010	0.009	0.021	0.22
	Lowland	0.000	0.010	0.022	0.14
	Woodlands	0.000	0.012	0.002	0.2[illegible]

Table 13

Subj. 7

Radioactivity (pCi/g. dry wt.) in Pinus taeda[1]

Plant Part (years)	Habitat	Cs-137	Mn-54	Ce-144	Ru-106
Leaves (1964)	Highland	3.5	1.6	7.1	2.8
	Lowland	5.1	5.8	5.4	2.9
	Woodlands	3.4	2.2	5.1	2.2
Leaves (1963)	Highland	6.4	4.3	31.0	10.0
	Lowland	4.9	3.5	21.0	7.6
	Woodlands	6.5	7.4	36.0	11.0
Twigs (1964)	Highland	3.4	1.1	25.0	2.7
	Lowland	4.2	3.7	3.3	1.6
	Woodlands	2.7	1.3	3.1	1.4
Twigs (1963)	Highland	4.0	2.6	15.0	6.0
	Lowland	3.2	5.3	13.0	5.4
	Woodlands	2.5	2.2	9.1	3.7
Cones	Highland	3.0	0.30	1.6	0.65
	Lowland	3.3	0.71	0.9	0.33
	Woodlands	2.5	0.40	1.0	0.33
Cork	Highland	2.1	1.0	3.9	2.9
	Lowland	1.7	0.8	3.0	2.8
	Woodlands	1.7	0.9	3.3	3.3
Phloem	Highland	2.00	3.50	0.72	1.20
	Lowland	3.80	11.00	1.10	1.20
	Woodlands	2.10	3.90	0.43	0.86
Wood (58-64)	Highland	0.35	1.20	0.06	0.28
	Lowland	0.48	3.80	0.24	0.47
	Woodlands	0.11	0.09	0.01	0.02
Wood (53-58)	Highland	0.27	1.20	0.08	0.27
	Lowland	0.38	4.00	0.22	0.48
	Woodlands	0.08	0.10	0.02	0.03
Wood (48-53)	Highland	0.15	0.69	0.04	0.12
	Lowland	0.47	4.20	0.24	0.55
	Woodlands	0.01	0.09	0.01	0.05
Wood (43-48)	Highland	0.22	0.65	0.04	0.15
	Lowland	0.53	3.10	0.15	0.45
	Woodlands	0.11	0.11	0.01	0.06

[1]Data averaged fro 5 samples representing 22-370 grams dry material/sample

Table 13

Radioactivity in Pinus taeda (cont.)

Subj. 7

Plant Part (years)		Sb-125	Zr-95	Zn-65	K-40
Leaves (1964)	Highland	0.51	0.17	0.13	1.2
	Lowland	0.19	0.06	0.33	1.5
	Woodlands	0.34	0.08	0.39	1.7
Leaves (1963)	Highland	2.30	0.43	1.99	3.6
	Lowland	1.50	0.24	1.40	2.6
	Woodlands	2.60	0.00	1.40	2.2
Twigs (1964)	Highland	0.44	0.25	0.07	1.1
	Lowland	0.14	0.05	0.16	1.1
	Woodlands	0.11	0.04	0.14	1.4
Twigs (1963)	Highland	0.57	0.15	0.90	1.9
	Lowland	0.49	0.15	0.74	1.5
	Woodlands	0.34	0.09	0.51	1.3
Cones	Highland	0.06	0.00	0.07	1.0
	Lowland	0.01	0.00	0.03	0.6
	Woodlands	0.05	0.89	0.05	0.6
Cork	Highland	0.49	Trace	0.35	0.6
	Lowland	0.51	0.04	0.19	0.5
	Woodlands	0.62	0.90	0.25	0.6
Phloem	Highland	0.150	0.084	0.058	1.10
	Lowland	0.200	0.140	0.013	1.00
	Woodlands	0.000	0.021	0.021	1.20
Wood (58-64)	Highland	0.000	0.000	0.017	0.13
	Lowland	0.059	0.000	0.004	0.08
	Woodlands	0.002	0.001	0.003	0.09
Wood (53-58)	Highland	0.005	0.007	0.017	0.05
	Lowland	0.021	0.039	0.000	0.11
	Woodlands	0.003	0.002	0.002	0.08
Wood (48-53)	Highland	0.009	0.013	0.001	0.09
	Lowland	0.024	0.028	0.000	0.13
	Woodlands	0.004	0.002	Trace	0.08
Wood (43-48)	Highland	0.004	0.008	0.002	0.15
	Lowland	0.000	0.000	0.006	0.15
	Woodlands	0.000	0.003	0.007	0.09

Table 14 Subj. 7

Radioactivity (pCi/g. dry wt.) in Juniperus virginiana

Plant Part	Habitat	Cs-137	Mn-54	Ce-144	Ru-106	Zr-95	K-40
Leaves[1]	Highland	13.0	17.0	76.0	30.0	2.5	5.7
	Lowland	10.0	12.0	72.0	26.0	1.6	7.4
	Woodlands	9.8	8.6	62.0	25.0	1.6	8.0
Twigs[1]	Highland	9.9	18.0	99.0	55.0	2.8	12.0
	Lowland	12.0	18.0	71.0	32.0	2.1	4.1
	Woodlands	7.8	14.0	76.0	6.2	1.7	8.5
Bark[2]	Highland	1.2	13.0	7.0	3.2	0.16	3.0
	Lowland	1.2	3.1	Trace	2.5	0.54	1.1
	Woodlands	2.0	1.7	Trace	3.0	2.50	1.0
Sapwood[2]	Highland	0.08	3.50	Trace	0.00	0.11	Trace
	Lowland	0.17	2.00	0.59	0.15	0.02	0.18
	Woodlands	0.21	0.04	0.09	0.05	0.00	0.06
Heartwood[2]	Highland	0.13	0.16	0.06	0.10	Trace	0.16
	Lowland	0.22	0.05	0.04	Trace	0.00	0.12
	Woodlands	0.14	0.05	0.00	0.17	Trace	0.04

[1] Data averaged from 10 samples representing 15-40 grams material/sample
[2] Data averaged from 6 highland, 3 lowland and 5 woodland samples representing 11-520 grams material/sample

Table 15

Radioactivity (pCi/1000 g) in soil

Collection Sites	Cs-137		Mn-54		Ce-144		Uranium (in mg)		Thorium (in mg)		K-40	
	T[1]	S[2]	T	S	T	S	T	S	T	S	T	S
Pinus[3]												
Highland	6.6	1.3	1.3	2.5	5.5	13.5	0.6	0.4	3.7	5.0	5.4	6.4
Lowland	10.0	1.5	1.8	0.5	9.4	2.2	0.1	0.1	3.7	3.9	6.7	5.8
Woodlands	3.3	0.2	0.8	0.8	2.8	0.6	0.9	0.8	3.0	2.8	1.9	2.2
Quercus[3]												
Highland	5.0	0.6	0.9	0.0	5.1	0.4	0.7	0.6	2.2	2.8	5.6	5.5
Lowland	36.0	3.0	4.8	1.2	47.0	3.5	1.4	0.7	3.2	1.9	7.7	5.6
Woodlands	4.4	0.2	1.4	0.3	3.7	0.1	0.9	0.7	2.1	3.1	5.3	4.8
Juniperus[4]												
Highland	11.3	0.8	2.4	0.6	12.6	0.7	1.6	0.9	4.9	3.0	4.4	6.1
Lowland	26.1	4.0	5.5	0.7	26.2	5.4	1.8	1.5	5.5	5.9	7.6	7.5
Woodlands	3.2	0.1	0.3	0.3	3.1	0.3	1.8	0.8	2.4	2.7	5.3	5.1

[1]Topsoil (0-4 cm depth) [2]Subsoil (12-20 cm depth)
[3]Data based on 10 g samples analysed 100 minutes, 5 samples
[4]Data based on 6 highland, 3 lowland and 5 woodland juniper soil samples

Subproject 8

Title: Gamma-ray patterns in certain small animals on Georgia's granitic outcrop.

Dates: April 1962 - September 1963.

Personnel: G. L. Plummer,
Technicians: J. D. Blake; T. M. Pullen, Jr.; J. B. Moncrief, Jr.

ABSTRACT

Among the insects and small vertebrates collected from granitic outcrops in Georgia during the summers of 1962 and 1963, grasshoppers in 1962 were the most radioactive group of animals sampled. Concentrations for cesium-137 ranged up to 41 pCi/g dry weight during 1962 in one species of grasshopper (Trimerotropis saxatilis) and may have climbed to as much as 80-100 pCi/g during 1963; another species (Romalea microptera) carried only 19 pCi/g in 1963 when fallout was at its peak. The total concentration in 1963 Romaleas for four fallout components (ruthenium-rhodium-106, cesium-137, zirconium-niobium-95, and manganese-54) was 120 pCi/g. All vertebrate animals sampled in 1963 contained less radioactivity. The skins of snakes, lizards, and birds carried cerium-praseodymium-144 and zirconium-niobium-95, whereas muscular tissues produced photon-energy peaks mostly for cesium-137 and potassium-40.

Reports: Plummer, G. L. 1966. Manuscript (submitted to Rad. Health Data and Reports). Department of Botany, University of Georgia, Athens.

Fig. 13. Net gamma-ray spectra (log scale) during 400-minute counting periods from insect collections.

A. Largge moths with ^{137}Cs peak (418 counts/400 min); 2.95 g dry wt; collected June, 1963, assayed June, 1963.

B. Smalll moths, beetles and leafhoppers; inconspicuous ^{137}Cs peak (74 counts/400 min) and ^{95}Zr Nb peak (81 counts); collected August, 1962, assayyed January, 1963.

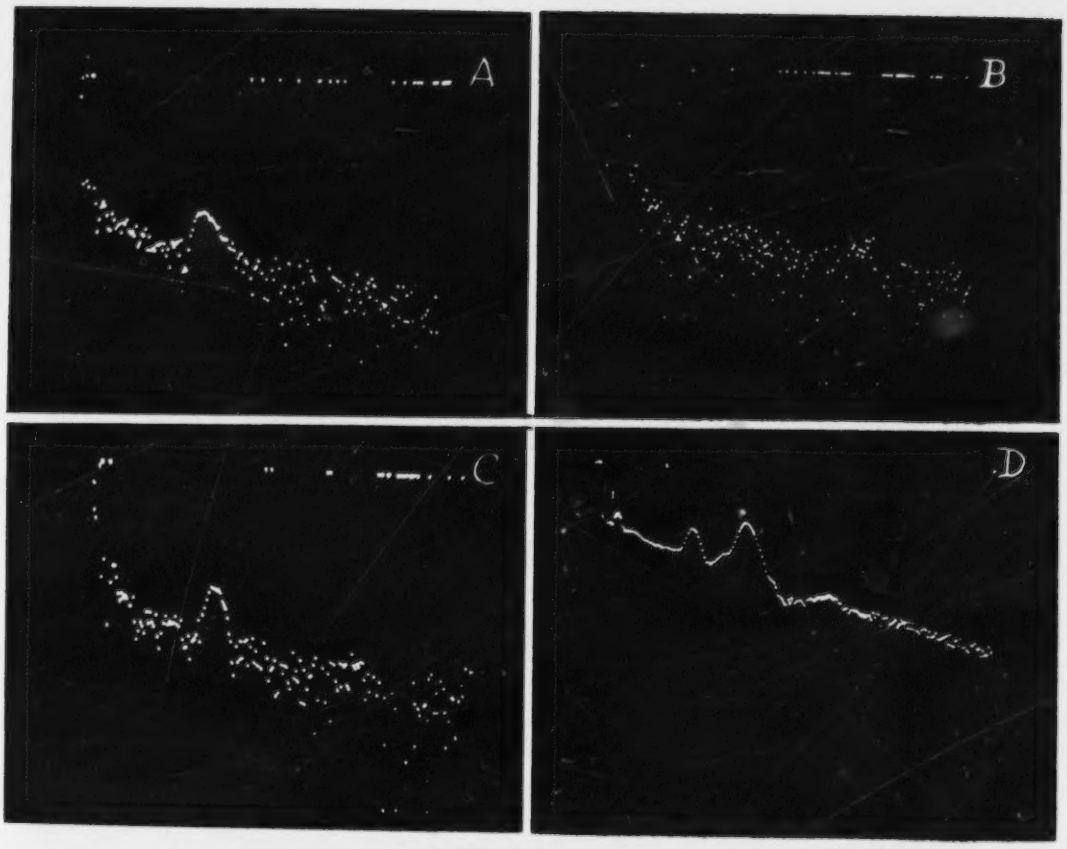
C. Trimerotropis saxatilis; ^{137}Cs peak (729 counts/400 min);; 2.56 g dry wt; collected September, 1962, assayyed January, 1963.

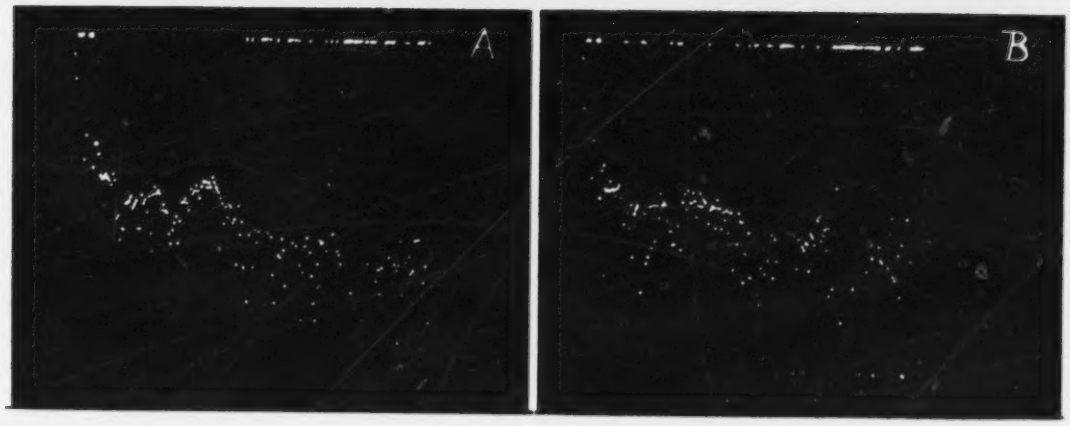
D. Romælea microptera; left to right, $^{144}CePr$, ^{106}Ru, $^{95}ZrNb$ (8,258 counts/400 min) (note: "hump" of ^{137}Cs between Ru and ZrNb, and ^{54}Mn on right slope of ZrNb peak); collected June, 1963, assayed June, 1963.

Fig. 14. Net gamma-ray patterns in vertebrates during 400-minutte counting periods.

A. Sceloporus undulatus, skin and feet, 2 specimens with (llarge peak) $^{95}ZrNb$ (228 counts/400 min); collected June, 1963, assayed October, 1963.

B. Sceloporus undulatus, skinless bodies with 10 pc of inconspicuous ^{137}Cs; assayed October, 1963.


A
B
C
D


A
B

Subproject 9

Title: Fallout in Georgia lichens.

Dates: January 1962 - June 1966.

Personnel: G. L. Plummer,
Grad. Resch. Assts.: A. R. Garrett; F. A. Helseth; J.D. Pittillo; J. N. Skeen; J. C. Ritchie.
Technicians: J. D. Blake; J. B. Moncrief, Jr.; T. M. Pullen, Jr.; F. M. Veal.

ABSTRACT

Concentration values for 9 radioisotopes are shown for three lichens that may be ecologically equivalent to similar taxons in the arctic tundras. ^{137}Cs in Parmelia conspersa during 1965 attained a mean concentration of 434 pCi/g dry weight, although the area-radioactivity was 32 nCi/m^2 which corresponds to about 42 per cent of the estimated available ^{137}Cs. Cladonia species generally held 0.1 of the radionuclides relative to biomass, but retained more radionuclides in a given area because more biomass occurred. Treatments with as much as 500 nCi/m^2 of ^{134}Cs showed no significant loss of radiocesium after lichens were leached with heavy rainfall. The results suggest that the capacity for Cladonia species to accumulate ^{137}Cs is, for a while, rather unlimited.

Reports: Plummer, G. L. 1966. Manuscript (submitted to Rad. Health Data and Reports). Department of Botany, University of Georgia, Athens.

Plummer, G. L. and Carol Atanasoff. 1966. Location and distribution of fallout radionuclides within lichen colonies. Manuscript (submitted to Mycologia). Department of Botany, University of Georgia, Athens.

Table 16

Concentrations of radioisotopes in populations of Parmelia conspersa at three geographic locations

Location 1964	Thor[1]	Ce-144	Ru-106	Cs-137	Zr-95	Mn-54	Zn-65	K-40
				(pCi/g dry wt)				
Georgia	0.41	394	363	313	5.1	55	5.9	68
Colorado	0.11	226	129	84	0.8	27	0	55
North Carolina	0.14	131	133	73	2.1	17	1.4	19

[1] Thorium data in milligrams

Subj. 9

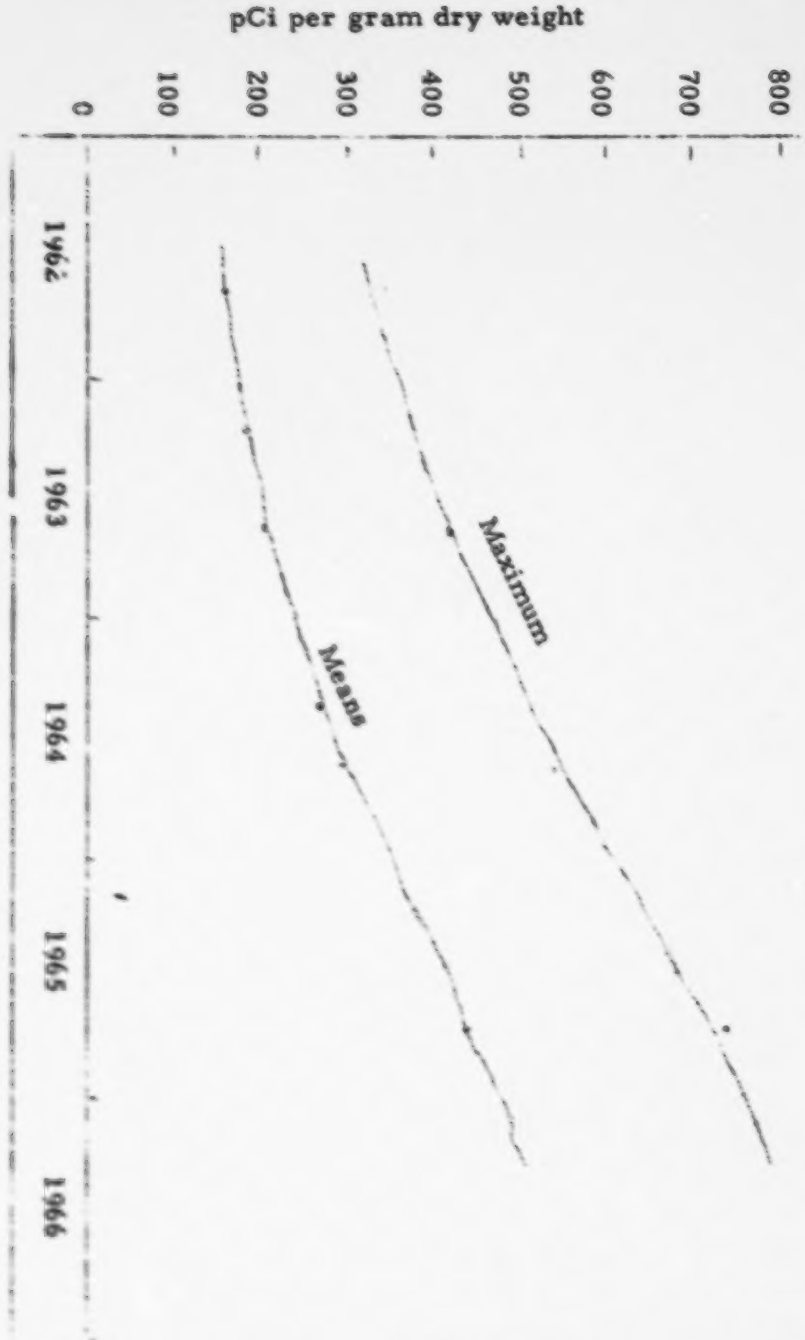


Fig. 15. Accumulation of ^{137}Cs in the lichen Parmelia conspersa from all outcrops.

Subproject 10

Title: Morphological heterogeneity in Andropogon growing on areas of high and low natural background radioactivity.

Dates: March 1965 - June 1966.

Personnel: James N. Skeen, grad. resch. asst.
B.S., Maryville College.

ABSTRACT

Field measurements on 1964 and 1965 mixed populations of the perennial broomsedges (Andropogon virginicus and A. ternarius) were made to determine whether or not gross morphological differences occurred in association with a 3-fold difference in the natural background radiation.

Although differences in gross morphology of Andropogon, expressed as number of culms per unit basal diameter, occurred in conjunction with differing levels of background radiation, a correlation has not been demonstrated between the number of culms and the background radiation level; that is, a cause and effect relationship is not implied. Further, since the direction of the differences was reversed in successive growing seasons, such differences cannot be accepted as valid indicator criteria of the prevailing natural radioactivity.

Although both the average number of culms per centimeter basal diameter and fallout radionuclides during 1964 were greater than the corresponding results during 1965, these relationships are probably coincidental even though very small amounts of ionizing radiation may stimulate certain kinds of plant growth.

Although Andropogon on low background-radiation areas produced a greater biomass than similar populations in high-background areas, these differences probably are not related to any kind of radioactivity; neither has an obvious relationship occurred between biomass and available plant nutrients. Such cause and effect interactions need more careful experimental design and analysis of the numerous interactions that occur in the field.

Therefore, variations in Andropogon morphology and biomass productivity, particularly within populations of the diploid A. virginicus, are believed to be influenced more by normal genetical and physiological mechanisms than by either natural radioactivity or by such level of fallout radioactivity as have existed for the past 4-5 years--the probable age of the populations investigated.

Reports: Skeen, J. N., and G. L. Plummer. 1966. Homogeneity in Andropogon growing on areas of high and low background radioactivity. Assoc. Southeastern Biol. Bull. 13:45.

Skeen, J. N. 1966. M.S. thesis. Department of Botany, University of Georgia, Athens.

Skeen, J. N., and G. L. Plummer. 1966. Bull. Georgia Academy of Science 24: 100-116.

Table 17

Concentrations of individual isotopes in each respective plant sample

Location and Sample	Isotope (All values expressed as pCi per g dry weight) Ce-144	Ru-106	Sb-125	Cs-137	Zr-Nb-95
High Areas:					
Shield's Pond					
1964	17.55	19.22	2.05	4.66	0.84
1965	2.29	2.63	0.27	1.02	0.20
Union Community					
1964	18.64	12.74	1.96	4.02	0.38
1965	1.36	0.99	0.53	1.66	0.08
Sugar Hill Community					
1964	22.87	15.55	3.15	2.37	0.62
1965					
Talmo					
1964	21.27	18.59	2.49	3.20	0.46
1965	1.34	0.87	0.30	1.47	----
Bluestone Creek					
1964	23.13	16.08	2.21	6.10	0.48
1965	3.63	1.57	0.63	1.50	----
Bowersville					
1964	19.39	13.73	1.69	2.23	0.88
1965	4.71	1.90	0.72	1.58	0.05
Low Areas:					
Gainesville South					
1964	14.13	11.21	1.63	3.13	0.26
1965					
Belmont					
1964	11.33	6.57	1.62	2.84	0.05
1965					
Airline					
1964	13.43	8.92	1.77	2.53	0.22
1965	0.72	0.47	0.19	.95	0.03
Pocataligo					
1964	11.43	7.54	1.41	2.79	0.18
1965					
McBean					
1964	17.56	18.36	2.01	4.63	0.75
1965	2.41	3.32	0.31	2.72	0.17
Stephen's Creek					
1964					
1965					
Brier Creek					
1964	21.21	14.80	2.11	5.33	1.17
1965	4.37	2.19	0.59	2.04	0.06

Table 17 Subj. 10

Concentrations of individual isotopes in each respective plant sample (cont.)

Location and Sample	Isotope				
	Cs-134	Mn-54	Zn-65	K-40	Co-60
Shield's Pond					
1964	----	2.48	0.30	1.95	Not Determined
1965	----	0.64	----	0.27	0.17
Union Community					
1964	----	2.39	0.51	1.71	ND
1965	0.35	0.13	----	0.51	----
Sugar Hill Community					
1964	----	6.48	0.90	2.21	ND
1965					
Talmo					
1964	----	5.69	0.55	2.24	ND
1965	----	0.47	----	0.67	----
Bluestone Creek					
1964	----	2.63	0.66	2.07	ND
1965	0.56	0.38	T	0.91	0.21
Bowersville					
1964	----	3.25	0.88	2.70	ND
1965	0.57	0.37	0.02	0.47	0.17
Gainesville South					
1964	----	2.79	0.37	1.39	ND
1965					
Belmont					
1964	0.46	0.92	0.16	0.96	ND
1965					
Airline					
1964	----	1.97	0.46	1.37	ND
1965	0.25	0.64	----	0.39	0.08
Pocataligo					
1964	----	1.55	0.27	1.13	ND
1965					
McBean					
1964	----	2.47	0.25	1.89	ND
1965	----	0.53	----	0.70	0.02
Stephen's Creek					
1964					
1965					
Brier Creek					
1964	----	1.87	0.62	1.95	ND
1965	0.08	0.51	----	0.40	0.36

The efficiency of detection instruments probably limits the accuracy of the above values to the nearest pCi; however, computed values are shown for purposes of relative comparisons.

Subproject 11

Title: Thorium, uranium and potassium in certain Georgia soils and their biological significance.

Dates: September 1964 - June 1967.

Personnel: Jerry C. Ritchie; grad. resch. asst.; 1964-1966.
M.S., University of Tennessee.

ABSTRACT

This study of soils collected in the Piedmont section of northeast Georgia indicated differences in gross relative gamma-ray activity among sites were as much as 10-fold. Differences in activity can be correlated best ($r^2 = -0.90$) with the concentration of thorium present in the soils.

Thorium concentrations in the soils averaged 15.6 ppm, for uranium 3.9 ppm, and for potassium 1.19%; the thorium to uranium ratio was 4.0.

A definite difference was established between gross relative activities of different soil series indicating that an increase in gross relative activity in a Georgia soil may be related to the soil series present at the site.

Reports: Ritchie, J. C., and G. L. Plummer. 1966. Assoc. Southeastern. Biol. Bull. 13:45.

Ritchie, J. C. Candidate for Ph.D. degree; dissertation proposed for June 1967. Department of Botany, University of Georgia, Athens.

Table 18

Subj. 11

Concentrations of natural gamma-emitting elements in selected locations

County	Sample	CPM/Kilogram[1]	Uranium ppm	Thorium ppm	Potassium %
3 x 3 well-type crystal[2]					
Columbus	1	1033	1.9	6.3	not detected
Screven	1	1083	1.9	6.6	not detected
Burke	1	1090	2.0	6.5	not detected
Hall	4	1532	1.3	10.7	0.35
Dekalb	1	2063	4.7	7.5	1.41
Jackson	2	2518	4.2	5.9	1.21
Henry	2	3052	4.5	17.6	1.98
Rockdale	1	7163	9.4	46.7	4.30
Jackson	3	8879	8.6	69.7	3.26
AVERAGE (75 samples)		2814	3.7	17.1	1.46
4 x 4 solid crystal[2]					
Hall	36	553	1.1	3.4	0.07
Screven	4	598	1.4	3.5	0.01
Burke	6	1008	2.8	5.4	0.04
Burke	5	1529	2.7	11.3	0.26
Madison	6	2182	7.8	10.8	0.89
Hall	3	3275	5.0	20.4	2.79
Madison	1	4056	8.3	27.2	1.23
Rockdale	6	4975	6.6	36.4	2.93
Jackson	9	5536	10.3	38.7	1.91
Hall	39	6301	3.3	51.0	3.82
AVERAGE (56 samples)		2170	4.1	13.7	0.83

[1]Gross relative gamma activity

[2]Use of different NaI(Tl) crystals did not affect results

Subj. 11

Table 19

Total gamma radioactivity vs. soil series

Soil series	Number of samples	CPM/Kilogram[1]
Madison	7	4408
Appling	9	3774
Cecil	25	2300
Norfolk	3	1366

[1]Gross relative gamma activity

Subproject 12

Title: Fallout radionuclides in white-tailed deer and browse.

Dates: June 1965 - August 1966.

Personnel: Thomas M. Pullen, Jr.
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ABSTRACT

The occurrence of ^{90}Sr and certain gamma-emitting fallout radionuclides in a food chain involving the white-tailed deer (Odocoileus virginianus) in the Georgia Piedmont was investigated.

Contamination levels of deer browse during the summer of 1965 were quite variable. ^{144}Ce, ^{106}Ru, ^{137}Cs, and ^{54}Mn were the most abundant gamma-emitting radionuclides present. Mean ^{90}Sr concentration in browse was about 55 pCi/g ash.

Male deer tissues obtained during November 1965 were found to contain only ^{137}Cs and ^{90}Sr in detectable amounts. ^{137}Cs was present in greatest concentrations in skeletal muscle tissues and in lowest concentrations in the liver. Mean ^{90}Sr concentration in mandibles was about 23.7 pCi/g ash.

Significant correlation was found between the ^{137}Cs levels present in the tongue and those found in thigh muscle, lung, kidney, and heart tissues.

The distribution of ^{137}Cs in the food chain of this area tended to follow the pattern which has been found in certain Arctic regions where reindeer (Rangifer tarandus) and caribou (Rangifer arcticus) have been reported to accumulate very high burdens of ^{137}Cs after having eaten a diet consisting principally of lichens.

Reports: Pullen, T. M., Jr. 1966. M.S. thesis. Department of Zoology, University of Georgia, Athens.

Pullen, T. M., Jr., G. L. Plummer, and E. E. Provost. 1966. (Manuscript adaptable for publication in Health Physics). Department of Botany, University of Georgia, Athens.

Table 20

Means and ranges of fallout radionuclide concentrations[1] in Greene County deer browse[2]

Radionuclide	Mean Concentration nCi/kg dry wt.	Range
^{144}Ce	4.676	1.8 to 10.1
^{106}Ru	4.172	1.7 to 8.1
^{137}Cs	1.672	0.7 to 2.8
^{54}Mn	1.503	0.5 to 3.2
^{95}Zr-Nb	0.821	0.2 to 1.7
^{125}Sb	0.652	0.2 to 1.5
^{60}Co	0.138	0.0 to 0.5
^{65}Zn	0.131	0.0 to 0.6

[1]Estimated error is less than or equal to ± 20 per cent of the values given
[2]Browse included 29 different genera and species

Table 21

Mean,[1] standard error, and standard deviation of ^{137}Cs concentrations in selected tissues of Greene County deer

Tissue	Mean Concentration nCi/kg wet wt.	Standard Error	Standard Deviation
Tongue (42)	4.645	0.34	2.24
Kidney (11)	4.009	0.51	1.70
Spleen (7)	3.400	0.47	1.25
Heart (10)	3.390	0.49	1.56
Lung (7)	1.971	0.36	0.95
Liver (9)	1.889	0.29	0.86

[1]Estimated error is less than or equal to ± 20 per cent of the values given

Table 22

Summary of ^{90}Sr content in deer bones, Greene County, Georgia

	Age Class Yrs.	No. in Sample	Mean pCi ^{90}Sr/g Ash	$s_{\bar{x}}$	s
Mandibles	1.5	7	25.42	1.49	3.94
	2.5	6	22.38	0.97	2.37
	3.5	2	21.60	3.23	4.59
Cannon Bones	1.5	1	15.8		
	2.5	1	27.5		
	3.5	1	26.1		

Subj. 12

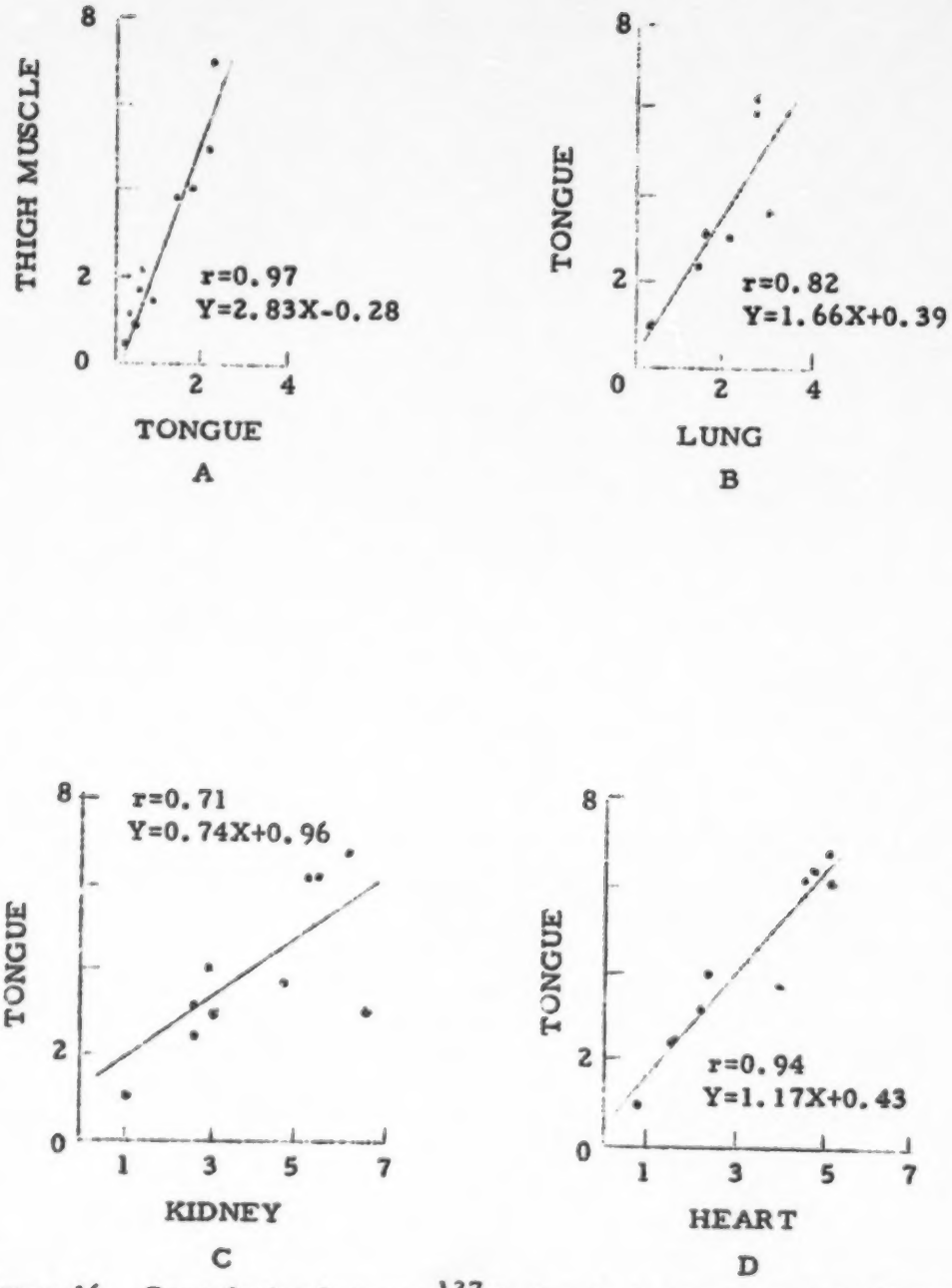

Figure 16. Correlation between ^{137}Cs levels in tongue and thigh muscle, lung and heart. (Data are in nCi/kg wet weight.)

DISCUSSION

The widely recognized hypothesis that available calcium has an effect on uptake of ^{90}Sr on the outcrops was neither accepted nor rejected by Subproject 1. Nevertheless, the low soil concentrations observed in summers, 1-7 ppm calcium, provide favorable conditions for incorporation of large amounts of radiostrontium by autumnal plants, such as Viguiera porteri, the outcrop sunflower.

Viguiera did accumulate ^{90}Sr in relatively large quantities (Subproject 2) for reasons explained early in the results. Other species also accumulated ^{90}Sr directly related to the position each species occupied along the water-way. However, an intimate knowledge of both the habitat and floristics is necessary to fully evaluate, or estimate, any implications of variations in concentration values among species. Differences in concentrations among plants may be easily recognized, but over-all significances of such differences, although interesting, may not be of spectacular biological importance because the plants are inconsequential economically and of unknown importance in food habit of wildlife in general.

Considerable radiostrontium came to Viguiera because not much of it was incorporated by the lichen Parmelia which did collect ^{137}Cs. Parmelia colonies which cover large areas on the outcrops pre-date the atomic era partly because of the very slow growth rates (Subproject 3). When certain colonies were treated with potassium in a nutrient solution, Parmelia grew exceptionally well. These observations suggest that ^{137}Cs was accumulated by Parmelia to compensate in part for probably low quantities of potassium ordinarily available for plant growth.

Studies on the movements and distribution of radionuclides within habitats (Subproject 4) showed that potassium was not abundant compared to agricultural soils and that ^{40}K was rather mobile, moreso than ^{137}Cs. Also, many fallout radionuclides usually were retained by the first habitat having a mineral-organic complex capable of base exchange. That first-habitat on the outcrops most often occurred at the water-inlet area of a community, which would be analogous to the top-most part of an ion-exchange column. Some ^{40}K flowed through the outcrop system quite easily, whereas, thorium probably did not move with water much beyond the point of origin. The occurrence of ^{54}Mn in Viguiera indicated clearly that both the ion-exchange complex of the habitat and bioaccumulation were functioning together. Viguiera happens to grow where manganese was most available.

Concentrations of radionuclides in many plant species (Subproject 5) suggested that lichens on the outcrops held more ^{137}Cs than arctic lichens; also, radioactive fallout in Georgia was large enough to monitor ^{137}Cs rather closely. Not only were the outcrop plants rather high in certain kinds of nuclides, but so were other plants, especially the common bermuda grass (Cynodon dactylon). Above average annual precipitation (more than 50") between 1959 and 1964, together with a southerly location of the "jet-stream" in early 1962 and 1963 were associated the unusual concentrations observed.

The isotopes ^{137}Cs and ^{54}Mn were collected independently of each other by trees on the outcrops (Subprojects 6, 7). Most striking was the occurrence of these nuclides in wood laid down prior to the atomic era that began in 1945. The occurrence of radioisotopes in 1938 wood came about by more than diffusion processes alone because the isotopes were concentrated in certain annual increment groups, in other words, no gradual diffusion gradient existed from recent sapwood to 1938 heartwood. These matters lead directly to certain unexplained physiological processes dealing with translocation problems in trees.

Animals on the outcrops (Subproject 8) usually have territories that extend more widely into the nearby fields and woodlots. Radioactivity in those herbivores during 1963 ranged up to 19,000 nCi/kg for ^{137}Cs in the Romalea microptera grasshopper. (Reindeer in Scandanavia have carried 60 nCi/kg in muscle tissue; Georgia deer in 1966 carried 0.5-2 nCi/kg.) The grasshoppers were rather short-lived and ate annual plants during May and June that not only held depositional fallout but fallout also incorporated through the root systems. Other animals were much less radioactive, that is, birds, lizards, mice and the like generally held less than 10 pCi/g body weight of all gamma-emitting isotopes and in some animals much of that radioactivity occurred on the skin.

Concentrations of radioisotope fallout in lichens on the Georgia outcrops are probably higher than any such reports to date. Data for Alaskan lichens and Scandavian lichens indicate Georgia Cladonia holds more ^{137}Cs than tundra Cladonia. Georgia Parmelia held more ^{137}Cs than Cladonia; ^{137}Cs in Parmelia during 1966 ranged up to 700 pCi/g dry weight Georgia Parmelia contained more radioactivity than Parmelia from North Carolina and Colorado in 1964. Experiment with ^{134}Cs indicated very little radiocesium leached from the plant body; thus, concentrations of ^{137}Cs increased almost directly proportional to what come to the lichen in rainfall. An exception,however, was when heavy rains bearing ^{137}Cs arrived on water-saturated lichens much of that radioisotope was then carried to the next plant species.

The perennial broomsedge grass (Andropogon virginicus) accumulated somewhat less radioactivity than other species due, in part, to its position at the lower end of the "filtration column" of species ahead or surrounding it. Nevertheless, that broomsedge is a diploid having such an arrangement of chromosomes that it is likely to be more sensitive to radiation than other broomsedge species on the outcrop. Experiments with it in a gamma-ray field and measurements of morphological variations (Subproject 10) indicated that natural heterosis is like to cause more variation in plant morphology than either fallout or natural radioisotopes.

Natural radioisotopes in the Georgia Piedmont (Subproject 11) are primarily thorium, potassium and uranium. Background radiation is due mostly to the thorium series and ^{40}K. Thorium concentration ranged up to 69 ppm and uranium up to 10 ppm,but no direct or indirect relationships occurred between the two in any combination of soil series. Generally, however, the Madison soil series contained about twice the radioactivity as the Cecil series--one of the most widespread soils in the Georgia Piedmont. The Coastal Plain sand--Norfolk loamy sand--was among the least radioactive, although not the least. Peach orchards frequently occur on high sandy sites where thorium and potassium are "above normal" in the soils. Fortunately, thorium is not an abundant metabolite in plants, but remains complexed in the chemistry of soil particles.

The best food chain study in this project involves that of the white-tailed deer (Subproject 12). Radioactivity in browse "desired" by the deer did not differ greatly from that in plants recognized as "undesirable" browse. Georgia deer accumulated as much and perhaps a little more ^{137}Cs as Colorado Rocky Mountain deer, but not as much as arctic reindeer. Concentrations of ^{137}Cs decreased slightly in 1966 deer samples compared to 1965 samples. Regressions which relate ^{137}Cs in tongue to that in other parts of the deer indicate nearly a 1:1 ratio; however, additional work underway may result in slight revision of this ratio.

CONCLUSIONS

Radioisotopes in the Georgia Piedmont have been similar to those commonly reported in radioactive fallout and to those usually associated with natural background radioactivity. Of prime importance, of course, were ^{137}Cs and ^{90}Sr. No new radioisotopes occurred within the biogeochemical dynamics of ecological systems on the outcrops; however, ^{54}Mn concentrations during 1963 were large enough to give that isotope third-place interest. All other fallout radionuclides occurred in concentrations that were not particularly unusual from the standpoint of previously reported characteristics. Concentrations of natural radionuclides in soils and rocks from areas near the outcrops were within quantities previously described for parts of the Coastal Plain region.

Various kinds of evidence suggest that as much as perhaps 200 mCi/sq mi of ^{90}Sr has accumulated since 1945 in some soils throughout the Piedmont; thus, deposition of ^{137}Cs probably ranges from 300 to possibly 400 mCi/sq mi during the same period.

The lichen Parmelia conspersa has incorporated ^{137}Cs almost linearly and grow in places where approximately half the total input of radiocesium may yet be collected. On the other hand, ^{90}Sr is not accumulated by the lichen as effectively as cesium. Because ^{137}Cs did not leach very much from the lichen, concentrations are expected to increase as long as the amount of cesium in fallout exceeds the rate of radioactive decay; and ^{90}Sr concentrations are not so likely to increase as abundantly as ^{137}Cs. Parmelia therefore will probably be a good indicator of total fallout that occurs in the Piedmont region.

Thorium and daughters contribute considerable radioactivity to the background. Ratios between thorium and potassium vary slightly from one place to another and the magnitude of the range from "high" background to "low" quantities varies by a factor as large as 11.

Although certain grasshoppers were the most radioactive animals observed during the 5-year study, these were not particularly abundant and the life-span was only about 5 weeks. Otherwise, the food-chains that supported white-tailed deer indicated that deer get about as much radioactive fallout in "prefered" plants as they would in less palatable species. Deer usually are not so dependent upon lichens as are the cervidae in the arctic tundra environments; therefore, concentrations of ^{137}Cs and ^{90}Sr in Georgia deer are lower than similar animals in the far north. Some evidence was associated with deer tongues to suggest the possibility of their use as indicators of possible body burdens of ^{137}Cs.

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